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CONTENTS

Volume 232 No 3101

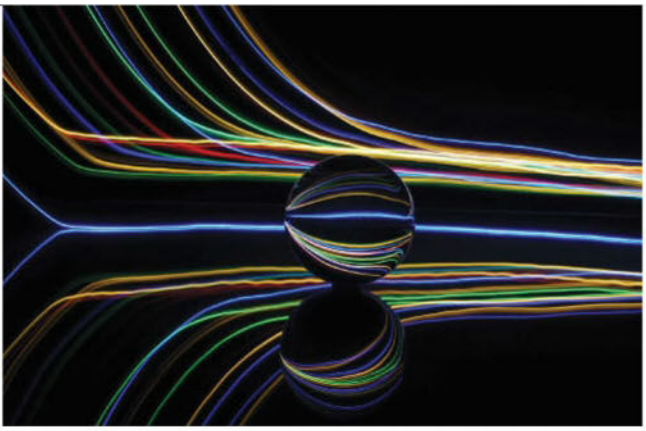
This issue online
newscientist.com/issue/3101

News

8

Over the limit

Was light once faster than gravity?


MANUELA SCHEWE-BEHNISCH/EYEEM/GETTY

On the cover

30

Tiny revolutions

Big physics has drawn a blank. It's time to think small

34 Hurt blocker
Chronic pain's brain toll
9 Deepest water
"Ocean" 1000 km down
8 Over the limit
Light faster than gravity?
24 Unfiltered
How to burst your Facebook bubble
39 Instant expert
Artificial intelligence: inside the black box

New Scientist

UNFILTERED How to burst your Facebook bubble

TINY REVOLUTIONS

Big physics has drawn a blank. It's time to think small

INSTANT EXPERT Artificial intelligence: inside the black box

Cover image
Dmitry Steshenko/Shuttertock

People

44

The gene tweaker

Wielding genes to fight previously untreatable conditions

KEN RICHARDSON FOR NEW SCIENTIST

Coming next week...

Booze ruse

What are the benefits of drinking in moderation?

Why lies win

We accept convenient untruths, but we can throw off the blinkers

rbi reed business information

recycle
When you have finished with this magazine please recycle it.

Leaders

5 The shape of post-Brexit science becomes clearer. Tackling pain in the brain

News

6 UPFRONT
Alarm over melting ice. Mapper of lightning. SpaceX plans a satellite fleet
8 THIS WEEK
Seeing time as a calendar. Ocean of water found 1000 km down. The wish list of planets to check for life. Stress-free phobia busting. Ants farm fruit and build plant cities
14 IN BRIEF
Oldest bone jewellery. Lab-built pulsing gut. When Mars was warm. New prime number

Analysis

18 Biological boundary Time to let labs grow human embryos beyond the 14-day limit
20 COMMENT
A new hype? Talk of starship drives returns. Medics needed to help end the war on drugs
21 INSIGHT
US and China in a gene-editing space race?

Technology

24 How to burst out of Facebook's filter bubble. Chinese attraction uses face recognition for entry. Making energy from waste hot water

Aperture

28 The invisible US-Mexico border

Features

30 Tiny revolutions (see above left)
34 Hurt blocker Tackling chronic pain's toll on the brain
39 INSTANT EXPERT Artificial intelligence: inside the black box
44 PEOPLE
Alessandra Biffi fights diseases (see left)

Culture

46 Our pick of 2016 First contact, stone-age political brains, a gloriously reinvigorated TV classic and much more
48 Gift books Great reads that you can win

Regulars

52 LETTERS Nostalgia not as good as it was
55 CROSSWORD
56 FEEDBACK The joy of movement
57 THE LAST WORD Ocean dwellers

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Give and take

The shape of post-Brexit science is becoming clearer

"LET'S see the fine print and the context… if it's not written on the side of a bus I don't believe it." That was the acerbic reaction of one academic to Theresa May's promise last Monday to invest an extra £2 billion a year by 2020 "to help post-Brexit Britain at the cutting edge of science and tech".

The fine print and context had not been supplied as *New Scientist* went to press, but others greeted the prime minister's pledge more effusively. Many were surprised by the size of the increase – the government says the amount currently spent on the "research base" is £6.3 billion, plus £2 billion in tax credits – and by the focus on commercially oriented research and development in industry.

So why now? Funding has been essentially static for a decade, but Brexit means getting "companies on an upwards trajectory before the rug's pulled out from beneath them", explained one innovation specialist. Tax incentives for R&D will also be reviewed under the government's proposals.

That's all very well. But the same day also saw the Commons pass the Higher Education and Research Bill, which would replace the councils that award research grants with a single all-powerful body. It would create another such body with the power to start up, shape and shut universities.

Such changes could strengthen science's position in Britain, by creating a national champion for science and a more flexible educational landscape. But commentators are worried about the potential concentration of decision-making – and that research priorities may become politicised, compromising institutions' autonomy.

It may just be that the Bill is vaguely drafted. But British science has enough uncertainty already: given the potential loss of European funding, and hostility to student visas, further vagueness could prove damaging.

The government wants science to provide answers to economic problems. Fair enough. But for that to work over the long term, researchers must remain free to choose their own questions. ■

Make the pain stop

YOU may have done it: shrugged off someone's complaints of pain when there seems to be nothing physically wrong with them. That's true for professionals, too: doctors may dismiss people who complain of chronic pain, particularly if they are women or minorities. Any treatment tends to involve powerful, and potentially lethal, painkillers. That's fuelled a crisis of huge proportions. In the US, where opioid prescriptions are rampant, there were around 50 deaths from overdose per day in 2014. And opioids don't treat pain, only blunt how acutely it is felt.

There may be a way out. The key is to recognise that chronic pain has observable, measurable and potentially treatable effects on people's brains (see page 34).

That should force the medical profession to take complainants seriously. Understanding that the brain's wiring is implicated in chronic pain offers hope that some people could be treated with meditation or exercise.

It's important to be clear this is about the brain, not the mind. People with chronic conditions often resist them being described as psychological, for fear they will be dismissed. Whether those fears are well founded, in this case, that would be a misunderstanding – and a tragic one. ■

NASA/JPL-CALTECH

Where did all the ice go?

Polar ice hits record low

SOMETHING is rotten in the state of the Arctic. Temperatures there have been an extraordinary 20 °C higher than the norm at this time of year.

For a few days, the sea ice began melting at a time when it should have been forming fast. And even before this melt, the ocean had been freezing over so slowly that the seasonal extent of sea ice over the past month was already the lowest ever recorded at this time of the year.

These unprecedented events are the result of unusual weather. Cold air from the Arctic has spilled south as far as Beijing, resulting in unusually cold weather across large parts of Asia, while warm air has flowed north to replace it. Climate change may be increasing the likelihood of this kind of event, by weakening the fast winds that circle the Arctic and keep the cold air locked in.

Meanwhile, on the other side of the planet, the extent of sea ice around Antarctica is also at a record low for this time of year. The reason for this is not clear. Unlike in the Arctic, which has seen less and less sea ice over the past two decades, this pattern is actually bucking the trend in Antarctica, where there has been a slight increase in sea ice over this period.

In the Arctic, the freeze has now resumed, but as the planet warms, more bizarre events like this will undoubtedly occur. "What's happening is truly remarkable," says meteorologist Eric Holthaus. "It's a possible sign of a scary new era in which all bets are off."

Is coal Finnished?

FINLAND could become the first country to ditch coal for good. As part of its latest energy and climate policy, the nation is considering banning the burning of coal for energy by 2030.

> **"Coal could disappear from Finland. The more countries phase it out, the better for the climate"**

"Basically, coal would disappear from the Finnish market," says Peter Lund, a researcher at Aalto University, and chair of the energy panel at the European Academies' Science Advisory Council.

The groundwork for the ban already seems to be in place. Coal use has been steadily declining in Finland since 2011, and the nation heavily invested in renewable energy in 2012, leading to a near doubling of wind power capacity the following year.

As Nordic power prices kept dropping, Finland poured a further €80 million into renewable power this past February. Coal-fired power plants are being mothballed and shut all over the country, leaving coal providing only 8 per cent of the nation's energy.

An official announcement of intent will be made on 24 November, but the move wouldn't be set in stone. The strategy is due to be presented to the Finnish parliament in March.

But Lund sees growing global momentum as nations such as France and Canada phase out coal. "The more countries join the coal phase-out club, the better for the climate as this would force the others to follow," he says.

Big bother

MASS surveillance legislation, labelled by critics as the most pervasive and invasive in history, has been passed in the UK.

The Investigatory Powers Bill allows intelligence and security services, police and other public bodies to intercept, acquire and retain the bulk communications data of citizens, such as internet activity. The government says it needs such data to fight terrorism and crime.

The law also grants access to bulk personal data sets held by individuals, communities, groups and public services among others, and it permits equipment interference – or hacking.

The depth and reach of the law are worrying, says Ray Corrigan, a digital privacy observer and a lecturer at the Open University. He fears the implications of US agencies being granted access to collected information, especially with Donald Trump as president.

"We need to be very careful about building all-powerful mass surveillance tools because you never know who is going to get the keys," says Corrigan.

ROLAND WEIHRAUCH/EPA/ALAMY

The geese are getting flu

Bird flu is back

IT'S here, just in time to threaten your festive dinner.

H5N8 bird flu first appeared in 2014, but this year's strain seems more deadly. Migrating birds have already carried it to the Middle East and Europe, and it is expected to spread further. Dozens of poultry farms in Denmark, Switzerland and Germany are now infected, and last week, 9000 turkeys were killed on an infected farm in Hungary.

Unlike the 2014 strain, the virus is also killing wild birds, including swans and gulls. Ron Fouchier at the Erasmus Medical Center in Rotterdam, the Netherlands, says H5N8 has picked up new genes from flu strains in wild birds, which could be making it lethal to more species.

While humans have so far escaped infection, the World Health Organization says the risk "cannot be excluded". "You can't be complacent about these viruses," says Ab Osterhaus at the Research Center for Emerging Infections and Zoonoses in Hannover, Germany.

Lightning mapper

IT'S lightning like you've never seen it before: streamed, 24/7, from space.

On 19 November, the US's most advanced weather satellite yet was launched. The National Oceanic and Atmospheric Administration packed the Geostationary Operational Environmental Satellite-R with instruments that will improve weather forecasting across the US. Its charged particle detectors will also measure space weather caused by the sun.

GOES-R was fired into an orbit 36,000 kilometres above Earth. From there, it will scan the western hemisphere every 15 minutes and the continental US every 5 minutes. Areas of severe weather will receive special attention, with scans every 30 to 60 seconds.

"On board is the world's first lightning mapper to make it into geostationary orbit," says William Koshak at NASA's Marshall Space Flight Center, who helped develop the instrument.

The mapper will detect lightning within clouds, moving from one cloud to another and between clouds and the ground across North and South America.

Satellite confetti

SPACEX is aiming for satellite domination. Elon Musk's space firm wants to launch more satellites than are currently in orbit, with the aim of delivering superfast broadband to the entire world.

The satellites will orbit at between 1150 and 1275 kilometres above Earth. SpaceX plans to kick things off with an initial constellation of 1600 satellites followed by a further 2825, all of which will be put into four orbital shells to improve coverage. Details of the plans emerged last week in an application to the US Federal Communications Commission.

Each satellite will be able to provide internet access for anyone within a 2120-kilometre-wide ellipse underneath its orbit. SpaceX says the satellites will provide internet speeds of 1 gigabit per second per user, which is around 200 times faster than average current speeds.

Once SpaceX has around 800 satellites in orbit, its internet service will cover the majority of the world, getting millions of people online.

Similar projects are being developed by Airbus, Virgin Galactic and Boeing, among others.

GM mozzies get flight clearance

ON 19 November, the Florida Keys Mosquito Control District gave the green light to a plan to release genetically engineered male mosquitoes, despite local objections.

The mosquitoes have been developed by biotechnology firm Oxitec in Oxford, UK, and carry a gene that makes their offspring die early. The idea is that the GM males will mate with native female mosquitoes, and slash the population of mosquitoes carrying dangerous diseases such as Zika and dengue.

Similar initiatives have already been successful. A trial in Piracicaba, Brazil, also led by Oxitec, reportedly reduced dengue cases by more than 90 per cent. The Florida trial in Key West would only last a few months, ending when the last of the modified mosquitoes die off. In August, the US Food and Drug Administration approved the plan, saying it would have "no significant impact" on the environment in the long term.

Floridians, too, voted in favour of it in a ballot earlier this month. But in Key Haven, the part of Key West where the trial will occur, 65 per cent of residents oppose the idea.

The spread of Zika was especially worrying in the state, which saw some 200 cases – although none in Key West itself. Last week, the World Health Organization announced that Zika is no longer an international public health emergency, but the agency officials said they do expect the virus to continue to spread.

VICTOR MORIYAMA/GETTY

Release the mosquitoes

60 SECONDS

Heart rate on demand

Porpoises can choose their heart rate to control their oxygen intake and prevent nitrogen build-up in their bodies when diving. This may help explain mass strandings – if the animals relinquish heart rate control when startled by a loud noise for instance, this could lead to decompression sickness (*Current Biology*, doi.org/bthk).

More health data

Google's DeepMind has announced a five-year agreement with an NHS trust that will give it access to patient data to develop and deploy its healthcare app, Streams. The new partnership follows an earlier agreement, the details of which *New Scientist* first revealed in April.

Yes to gene editing

People affected by rare genetic disorders are mostly in favour of gene editing, according to charity Genetic Alliance UK. In a survey of 152 people, 83 per cent felt the benefits of gene editing outweigh any potential risks. But 86 per cent said gene editing should be limited to treating diseases, and shouldn't be used to enhance healthy people.

The big boom

Samples from inside Mexico's Chicxulub crater have provided a timeline of what happened when the cataclysmic asteroid struck. First it blasted through Earth's crust, lifting rocks from the bottom 25 kilometres into the air. A giant mountain range lifted and collapsed within three minutes and a peak of rock splashed upward like a fluid. Earthquakes topping the 10-point Richter scale then rattled the planet.

Less study, more sleep

Should you cram before an exam? Better to nap instead. Researchers at the Duke-NUS Medical School in Singapore found that volunteers who napped before a test scored just as well as those who revised – and they scored better a week later, too.

Gravity chased light after big bang

A varying speed of light solves big problems, finds **Michael Brooks**

MANUELA SCHEWE-BEHNISCH/EYEEM/GETTY

Getting up to speed

IT'S supposed to be the most fundamental constant in physics, but the speed of light may not always have been the same. This twist on a controversial idea could overturn our standard cosmological wisdom.

In 1998, Joao Magueijo at Imperial College London, proposed that the speed of light might vary, to solve what cosmologists call the horizon problem. This says that the universe reached a uniform temperature long before heat-carrying photons, which travel at the speed of light, had time to reach all corners of the universe.

The standard way to explain this conundrum is an idea called inflation, which suggests that the universe went through a short period of rapid expansion early on – so the temperature evened out when the cosmos was smaller, then it suddenly grew. But we don't know why inflation started, or stopped. So Magueijo has been looking for alternatives.

Now, in a paper to be published 28 November in *Physical Review*, he and Niayesh Afshordi at the Perimeter Institute in Canada have laid out a new version of the idea – and this one is testable. They suggest that in the early universe, light and gravity propagated at different speeds (arxiv.org/abs/1603.03312).

A testable theory

If photons moved faster than gravity just after the big bang, that would have let them get far enough for the universe to reach an equilibrium temperature much more quickly, the team say.

What really excites Magueijo about the idea is that it makes a specific prediction about the cosmic microwave background (CMB). This radiation, which fills the universe, was created shortly after the big bang and contains a "fossilised" imprint of the conditions of the universe then.

In Magueijo and Afshordi's model, certain details about the CMB reflect the way the speed of light and the speed of gravity vary as the temperature of the universe changes. They found that there was an abrupt change at a certain point, when the ratio of the speeds of light and gravity rapidly went to infinity.

This fixes a value called the spectral index, which describes the initial density ripples in the universe, at 0.96478 – a value that can be checked against future measurements. The latest figure, reported by the CMB-mapping Planck satellite in 2015, placed the spectral index at about 0.968, which is tantalisingly close.

If more data reveal a mismatch, the theory can be discarded. "That would be great – I won't have to think about these theories again," Magueijo says. "This whole class of theories in which the speed of light varies with respect to the speed of gravity will be ruled out."

But no measurement will rule out inflation entirely, because it doesn't make specific predictions. "There is a huge space of possible inflationary theories, which makes testing the basic idea very difficult," says Peter Coles at Cardiff University, UK. "It's like nailing jelly to the wall."

"We have a model of the universe that embraces the idea there must be new physics at some point"

That makes it all the more important to explore alternatives like varying light speeds, he adds.

The implications could be profound. Physicists have long known there is a mismatch in the way the universe operates on its smallest scales and at its highest energies, and have sought a theory of quantum gravity to unite them. If there is a good fit between Magueijo's theory and observations, it could bridge this gap, adding to our understanding of the universe's first moments.

"We have a model of the universe that embraces the idea there must be new physics at some point," Magueijo says. "It's complicated, obviously, but I think ultimately there will be a way of informing quantum gravity from this kind of cosmology." ■

In this section

- The wish list of planets to check for life, page 10
- Stress-free phobia busting, page 12
- How to burst out of Facebook's filter bubble, page 24

Synaesthetes 'see' calendar in front of them

WHEN you think about last April, what do you imagine? If you see a crisp image of a calendar in front of you, you might be a calendar synaesthete.

Only a few people have calendar synaesthesia. To find out if they are having a real sensory experience, a team led by Vilayanur Ramachandran at the University of California, San Diego, tested two synaesthetes.

One, known as ML, sees her months as occupying an asymmetrical "V" shape. When asked at intervals to draw her calendar on a screen using a laser pointer, the angles and lengths of the V shape were always identical.

ML also appears able to use her calendar to easily navigate backwards through time. When asked to recite every third month backwards, she took 1.88 seconds per month, compared with 4.48 seconds in eight non-synaesthetes (*Neurocase*, doi.org/bs3j). "During the task we noticed that ML appeared to be inspecting her calendar," says Ramachandran.

EA, another synaesthete, sees her calendar shaped like a hula-hoop in front of her chest. The calendar is stuck to her body and doesn't move with her eyes. Intriguingly, when turning her head to the right, she told Ramachandran's team that the months on the left of her calendar became "fuzzy", and memories of these months were harder to access.

We may all map time in space to some extent. We acquired the concept of time relatively recently in our evolutionary history, says Ramachandran, but the brain wouldn't have had time to evolve a specific area to deal with it. "Given the opportunistic nature of evolution, perhaps the most convenient way to represent the abstract idea of time might have been to map it onto a preexisting map of visual space," he says.

We all attend to various places in space when thinking about months or numbers, says Julia Simner at the University of Sussex, "albeit at a more subconscious level". Helen Thomson ■

MEDERIC PALOT

Priceless imperfection

Oceans of water in deep Earth go 1000 km down

JULES VERNE's idea of an ocean deep below the surface in *Journey to the Centre of the Earth* may not have been too far off. Earth's mantle may contain many oceans' worth of water – with the deepest 1000 kilometres down .

"If it wasn't down there, we would all be submerged," says Steve Jacobsen at Northwestern University in Evanston, Illinois, whose team made the discovery. "This implies a bigger reservoir of water on the planet than previously thought."

This water is much deeper than any seen before, at a third of the way to the edge of Earth's core. Its presence was indicated by a diamond spat out 90 million years ago by a volcano near the São Luíz river in Juina, Brazil.

The diamond has an imperfection – a sealed-off inclusion – that contains minerals that became trapped during the diamond's formation. When the researchers took a closer look at it with infrared microscopy, they saw unmistakable evidence of the presence of hydroxyl ions, which normally come from water. They were everywhere, says Jacobsen.

To work out the depth the diamond formed at – and hence the origins of this water – the team again turned to the inclusion. It is made of a ferropericlase mineral, which is composed of iron and magnesium oxide, and can also absorb other metals such as chromium, aluminium and titanium at ultra-high temperatures and pressures typical of the lower mantle.

"This water is much deeper than ever found before, at a third of the way to the edge of Earth's core"

Jacobsen found that these additional metals had separated from the ferropericlase – something that happens in the milder conditions a diamond experiences as it edges up through shallower depths. But for the metals to be present at all, the diamond must have originated in the intense conditions of the lower mantle (*Lithos*, doi.org/btcn). "Based on the composition of the trapped mineral, we speculate that the depth was around 1000 kilometres," says Jacobsen.

The clincher is that as the inclusion was trapped in the diamond the whole time, the water signature can only have come from the diamond's place of formation in the lower mantle. "This is the deepest evidence for water recycling on the planet," he says. "The big take-home message is that the water cycle on Earth is bigger than we ever thought, extending into the deep mantle."

His team has previously found evidence of massive amounts of water some 600 kilometres down, mixed in with rock.

"Water clearly has a role in plate tectonics, and we didn't know before how deep these effects could reach," he says. "It has implications for the origin of water on the planet." For example, it is possible that Earth had water from day one in the very dust and rocks that first formed it.

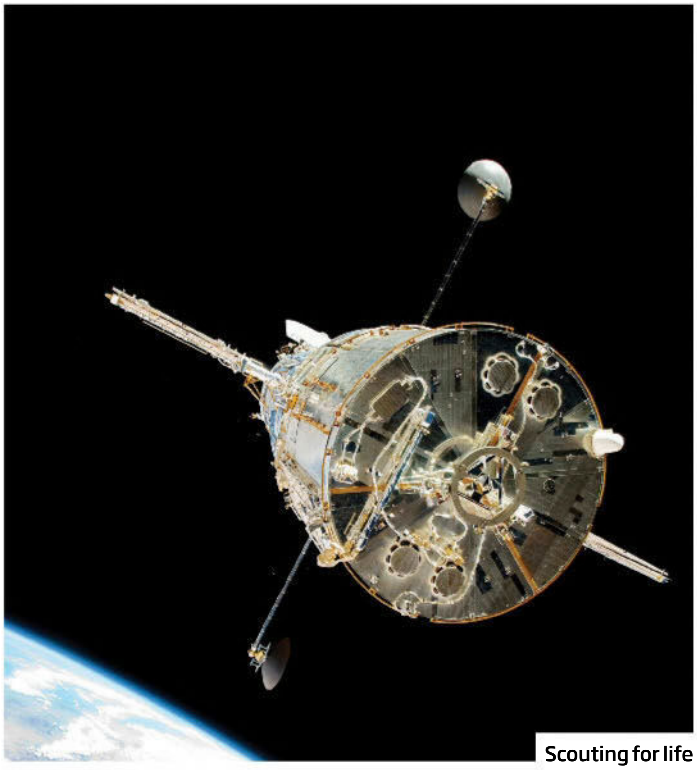
But it's still not clear exactly how water got so far down. It may have arrived in the mantle even earlier than 90 million years ago, through sedimentary oceanic crust burrowing downwards as primitive tectonic plates thrust against and past each other.

The new study suggests cycling of subducted material, even at these depths, says Lydia Hallis at the University of Glasgow, UK. "Ultimately, this research will help us better understand the way our planet recycles itself."

Jacobsen thinks that this water may help explain why Earth is the only planet we know to have plate tectonics. "Water mixes with ocean crust and gets subducted at convergent plate boundaries," he says. "Introducing water into the mantle promotes melting and weakens rock, likely helping out the motions of plates like grease."

The hope is that such research will yield insights into how our oceans and atmosphere formed in the first place. **Andy Coghlan** ■

Hubble to narrow hunt for alien life


NASA

Scouting for life

Joshua Sokol

THE search for alien life is taking a shortcut. The Hubble Space Telescope is set to spend hundreds of hours over the next year running reconnaissance on a shortlist of worlds to identify those we should scour for life first.

This latest effort aims to take advantage of Hubble's successor, the James Webb Space Telescope. Set to launch in 2018, JWST will have unprecedented power to detect the atmospheres of faraway planets for biosignature gases that would suggest they host living, breathing organisms.

But competition for JWST time will be fierce. And there may not be time for much of a learning curve. The $8 billion telescope is supposed to last at least five years, but if something breaks, it can't be fixed. That's why it's important that Hubble narrows the field for JWST now. Here's an early look at Hubble's itinerary.

THE EXO-VENUS

Hubble has already started studying GJ 1132b, a planet 40 light years away that was first spotted in May 2015. It's very close to its star and so probably too toasty to host life, but we can use it to practise measuring the atmosphere of a rocky world.

Many of the first planets JWST will study are orbiting small, cool M dwarf stars, whose outbursts might erode planets' atmospheres (see "Look to the stars", right). Observations by Zach Berta-Thompson at the University of Colorado at Boulder last year hinted that GJ 1132b was surrounded by a cloud of neutral hydrogen – a sign it was losing its gas to space, which may render it uninhabitable. More in-depth observations may confirm the rate at which its atmosphere is leaking, and may identify specific molecules.

THE SUPER-EARTHS

Either K2-18b or K2-3d, two planets discovered in the second phase of the Kepler mission, might have the whole package. Both orbit bright nearby stars that could reveal their atmospheres, and are at the right distances for both to host liquid water.

The only obviously weird thing about these planets is their size. Both are super-Earths, wider than our planet. K2-3d is 1.6 times larger than Earth and likely rocky; K2-18b is 2.3 times larger and may have a thick, puffy atmosphere.

Hubble will spend about five days over the next year studying these planets. Both might have hydrogen-rich atmospheres, or be completely blanketed by clouds, says Björn Benneke at the California Institute of Technology.

But if the molecular signature of water, methane or ammonia shows up on either planet, it would mean we have a real chance to look for biosignatures. "If we found any signal, then we would hit this pair extremely hard with James Webb," Benneke says. "There's no doubt about that."

THE TRIPLETS

One ultra-cool dwarf star, TRAPPIST-1, offers a discount rate: three planet siblings, all within about 20 per cent Earth's size. Of those three planets, announced in May 2016, one or two might be water-friendly.

Later this year, the team that discovered the triplets used Hubble to find that two of the planets lack big, puffy atmospheres, which suggests they are rocky. This December and January, they will use Hubble again to measure how thick the atmospheres are, says Julien de Wit at the Massachusetts Institute of Technology. Their findings will help them plan a proposal to study the triplets during JWST's first year.

THE NEXT-DOOR NEIGHBOUR

You couldn't find a closer potentially habitable planet than Proxima b – an Earth-sized world around the next star over – if you tried. But Proxima b has a downside: it never transits in front of its star, making it far harder to study.

All is not lost. We could look for the planet's phases: minute changes in the system as the planet orbits its star and points different faces at Earth.

If JWST saw heat speeding from one side of the planet to the other, it would show that the planet has an atmosphere in the first place, says Laura Kreidberg at Harvard University. Or with a few months of solid staring by JWST we might be able to detect ozone, a possible biosignature, in its atmosphere. ■

LOOK TO THE STARS

A good world is hard to find - but that's only half the battle. "Context is everything in many aspects of life," says Evgenya Shkolnik at Arizona State University. "In the case of exoplanets, that context is the star."

Shkolnik is leading an effort to spend about a week using Hubble to observe small, cool M dwarf stars to understand effects that could hide life on their planets, or give a signal that looks like life but isn't.

Habitable-zone planets around M dwarfs are subject to erratic bursts of ultraviolet radiation, which would destroy biosignature molecules in an atmosphere. UV radiation can also break up water, which could increase the concentration of oxygen even with no living organisms responsible.

Ultraviolet radiation is harmful to life on its own, too. So the star's temperament will play a key part in deciding whether to study a planet.

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Beating fear without feeling it

Clare Wilson

NO NEED to face your fears, they can be made to just melt away. It seems that nudging people into unconsciously thinking about scary things can help them to unlearn their associations of fear.

Phobias are usually treated with "exposure therapy", which involves seeing the stuff you are frightened of while in a safe environment. But many people find it so stressful that they drop out – or won't even sign up. "We thought if we can do it unconsciously, there's no unpleasantness," says Hakwan Lau at the University of California, Los Angeles.

Lau's team is using software that can be trained to tell what people are thinking about as they lie in an fMRI scanner. This software can even identify things that someone is thinking about unconsciously, by focusing on activity in the visual cortex, which processes data from our eyes and is involved in visual recall.

Using this, the team has found a way to make people think about scary things without realising. The group recorded the patterns of brain activity that volunteers had when shown a variety of 40 images – including some common subjects of phobias, such as spiders and snakes.

Next, whenever a volunteer's unconscious patterns of activity in their visual cortex matched those generated by seeing a scary picture, they were given a cash reward. This "neurofeedback" training encouraged them to think about the scary thing even more, but unconsciously. "They had no clue what they were doing. They think they're doing a mental exercise to get money," says Lau.

To see if this unconscious exposure technique can reduce phobia-related stress, the team tried it on people who had been conditioned to be scared of a pattern of coloured lines by giving them small electric shocks when shown that pattern. After about 3 hours of neurofeedback training, their fear of the lines was much reduced (*Nature Human Behaviour*, doi.org/btcz).

The team told the Society for Neuroscience conference in San Diego, California, last week, that the technique has now been tried on natural fears. The group asked 30 people to choose two pictures they found most scary from the set of 40 images. After doing neurofeedback training on the subject of one of these pictures – for example, a dog – the participants sweated less when they were shown that picture, and had reduced activity in their amygdalae, the brain's fear centres. There was no such change when shown the scary picture for which they hadn't had neurofeedback training.

PAUL WATERMAN/EYEEM/GETTY

Don't think about that spider

The team plans to go back to the participants in three months and ask them if they still feel scared of their chosen animals. Only then will we know if this approach works, says Joe LeDoux of New York University. "Self-reporting of fear is the gold standard for whether a person has been successfully treated."

If it works, it might help with other fear-related conditions, such as post-traumatic stress disorder and anxiety. "We are indirectly influencing the unconscious mind," says Lau.

LeDoux is also investigating unconscious exposure therapy, by showing people pictures of their phobias for a fraction of a second – so fast they only register subliminally. He thinks both approaches would need to be followed up with talking therapies to help people change their conscious beliefs – but this should be easier once unconscious fear has been reduced. ■

Ants grow plant cities and farm tropical fruits

A FIJIAN ant first started planting fruit crops 3 million years ago, long before human agriculture evolved. The ant, *Philidris nagasau*, grows and harvests *Squamellaria* fruit plants on the branches of various trees.

As far as we know, only a handful of other species farm their food. Ants have been known to cultivate fungi, but this is the first time they have been found planting crops in a mutually beneficial manner.

First, the ants insert seeds from the fruit plant in cracks in the tree bark. Workers then patrol the planting sites and fertilise seedlings with faeces.

As the plants grow, they form large, round hollow structures at their base called domatia that serve as nests for the ants. When the fruit appears, the ants eat the flesh and collect the seeds for future crops.

Guillaume Chomicki at the University of Munich, Germany, and his colleagues discovered that each ant colony farmed dozens of *Squamellaria* plants at the same time, with trails linking each thriving hub. The plant cities often spanned several adjacent trees.

The plants are completely dependent on the ants to cultivate and fertilise their seeds. And the ants cannot survive without the food and shelter provided by the plants. Chomicki team's genetic analysis showed that the mutualistic association is around 3 million years old (*Nature Plants*, DOI: 10.1038/nplants.2016.181).

"Ants are a lot smarter than we think they are – they form networks that are much like our brains"

The fact that ants have developed such sophisticated food production skills confirms their impressive teamwork, says Kirsti Abbott at the University of New England, Australia.

"Ants are a lot smarter than we think they are – we call them superorganisms because they form networks that are much like our brains," she says. "The information flow among ant colonies is just insane compared with human social systems." Alice Klein ■

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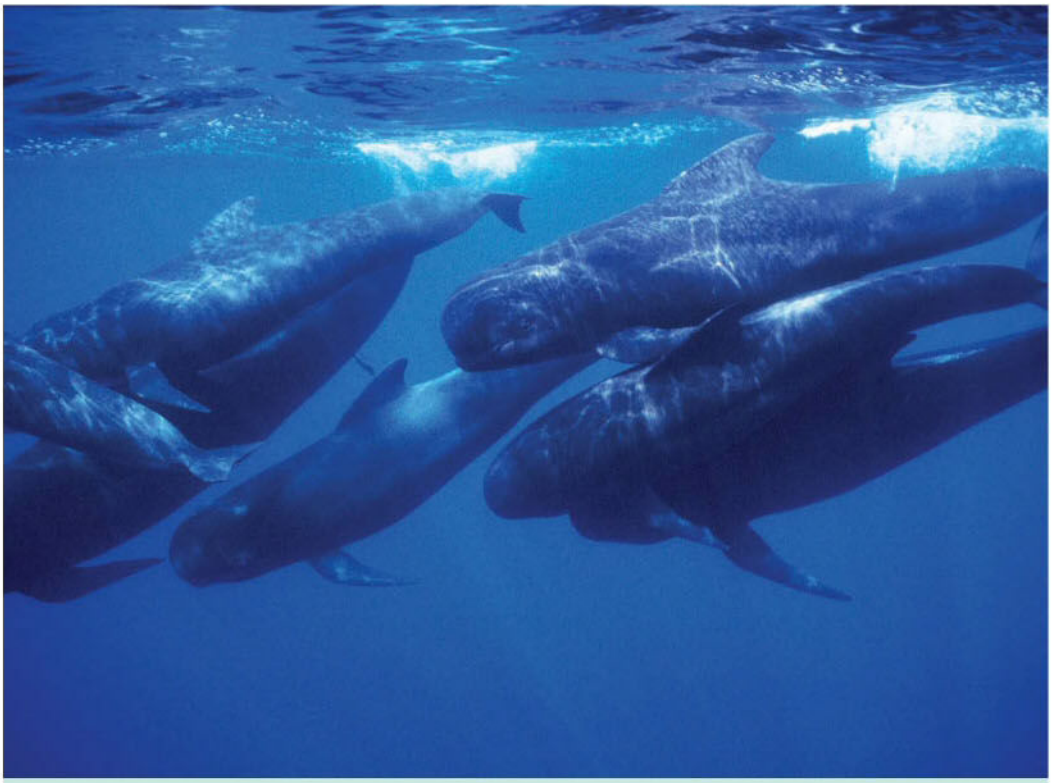


ROLAND SEITRE/NATUREPL.COM

Pilot whales babysit each other's young – but why?

IT'S a whale of a job. Rather than sticking exclusively to their mothers' side, baby pilot whales in the north Atlantic take turns swimming next to other adults.

Pilot whales live in multigenerational family units of about two to four dozen individuals, says Joana Augusto at Dalhousie University in Halifax, Canada. Those units often gather in larger groups that stay together for a few weeks, allowing whales to socialise. And while anecdotal evidence suggests calves sometimes accompany members of the gang that aren't their mothers, nobody had systematically studied such behaviour in pilot whales before, Augusto says.

Her team studied a population of more than 3000 long-finned pilot whales off Cape Breton Island in Nova Scotia, Canada. They photographed and identified whales based on physical marks such as nicks in their dorsal fins.

During more than 600 encounters over three years, the team spotted 356 identifiable calves, and about a quarter of them sometimes stuck close to adults that weren't their mothers, both male and female (*Marine Mammal Science*, doi.org/bs72). It is unclear why a male might let a baby stay by his side, but one possibility is that he is showing off in front of the females. The calves might benefit, too, Augusto says. "The calf might be learning from experiences with different individuals of how they should be behaving socially."

Lab-grown gut pulses like the real thing

GUT tissue wired up with nerves has been grown in the lab and successfully grafted into mice for the first time. The achievement could improve our understanding of inflammatory bowel disease and Crohn's disease.

"I feel this is one of the most complex tissues to have been engineered," says Jim Wells of Cincinnati Children's Hospital Medical Center in Ohio. "It has the inner lining that does all the absorption of nutrients and secretion of digestive juices, fully functional muscles that propel the food through the gut, and nerves that control the pulsed muscle movement."

Wells and his team made the tissue by converting either skin or white blood cells to induced pluripotent stem cells. Providing these with different nutrients and growth factors encouraged them to form intestinal tissue and nerves (*Nature Medicine*, DOI: 10.1038/nm.4233). The tissue could pulse both in the lab, and when small patches of it were grafted into the kidneys of mice.

If the tissue can be developed into gut transplants, it could help premature babies with short bowel syndrome. It could also be used to study constipation and diarrhoea. "These affect hundreds of millions of people," says Wells.

Enzyme that could stop Alzheimer's

WE MIGHT be able to prevent Alzheimer's disease by stopping a brain protein from going rogue, a study in mice suggests.

In healthy brains, tau protein is essential for normal cell functioning. But in Alzheimer's, tau clumps together, which is thought to harm the brain, and causes twisted tangles to form.

Now Lars Ittner at the University of New South Wales, Australia, and his colleagues have found an enzyme called p38-gamma kinase that controls tau's behaviour. The enzyme helps keep tau in a healthy, tangle-free state, preventing the onset of memory loss in mice that have been bred to develop Alzheimer's symptoms (*Science*, doi.org/bs9s).

In people, the amount of this enzyme declines as Alzheimer's progresses, so boosting it might prevent or treat the disease.

"I think this is very, very exciting," says Ittner.

New prime number has 9 million digits

BIG news for big numbers. There's a new entry in the Largest Known Primes Database, a list of numbers divisible only by one and themselves. It's $10223 \times 2^{31172165} + 1$, which is 9 million digits long.

A single computer would take centuries to uncover such a large number, but thousands of collaborators made the find in just eight days – thanks to the PrimeGrid website, where volunteers contribute spare computing power.

It's special for another reason: the discovery brings us one step closer to solving the 50-year-old Sierpinski problem, which seeks the smallest number for which the expression $k \times 2^n + 1$ is not prime, for any n. This proves that 10223 is not a Sierpinski number.

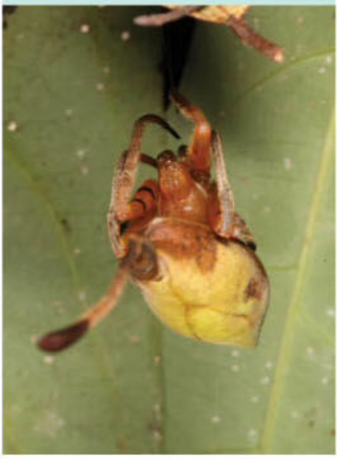
Spider looks like dead and live leaf

IT'S half dead. Or at least it would like you to think so. A spider found in the Chinese rainforest looks like a leaf that's both dead and alive at the same time – all to help it blend in and hide from predators.

Matjaž Kuntner at the Slovenian Academy of Sciences and Arts in Ljubljana stumbled across the spider on an expedition in Yunnan province. Shining a torch on strands of spider silk led him and his team to a suspicious looking patch of leaves. "It then became apparent that one of those leaves was not really a leaf," he says. "It was a spider."

The spider's back resembles a green, living leaf complete with veins, while its dull, brownish front looks more like a dead leaf. It even has an unusual abdominal extension reminiscent of a stalk.

The spider has a behavioural repertoire to complement its looks. On the living branch where the team found their first specimen, there were dead leaves hanging on strands of silk 2.5 metres up from the forest floor. Kuntner thinks the spiders haul leaves up from the ground and hang them up to create daytime hideouts that match their camouflage and protect them from predators. The team dubbed this feat the "ultimate leaf masquerade". At night the spiders can emerge and build webs to catch prey (*Journal of Arachnology*, doi.org/bs8h).



MATJAŽ KUNTNER

Kangaroo-bone nose piercing is oldest jewellery of its kind

THAT trend for nose piercing? Turns out it's so 44,000 BC.

A crafted bit of 46,000-year-old kangaroo bone found in Australia seems designed to be worn in the nasal septum, which would make it our oldest known bone jewellery. Only Neanderthal eagle talon necklaces and bracelets are older.

The finding shows that the first humans to reach the continent 50,000 years ago were as culturally advanced as their counterparts elsewhere.

Sue O'Connor at the Australian National University in Canberra found the delicate, 13-centimetre-long artefact in a rock shelter in the Kimberley region of Western Australia. Microscopic analysis by her colleague Michelle Langley revealed red ochre stains and scrapes down the side made by stone tools. Fractures in the artefact were consistent with a twisting, pushing action that resulted in a pointy tip snapping off, possibly as it was being driven through someone's nose.

Based on comparisons with 19th and 20th-century sewing needles and ornaments made by Indigenous Australians, the bone seems more likely to be jewellery than a tool. The artefact's shape, ochre staining and wear patterns closely match modern nose bones (*Quaternary Science Reviews*, doi.org/bs84).

The first arrivals would have adapted the bone-crafting skills they developed in Africa to the bones of Australian animals, says Langley. Kangaroo bones are hard, strong and easy to come by, making them good replacements for horns and ivory.

Monk seals filmed napping on seabed

IT'S the ultimate waterbed. Mediterranean monk seals have been filmed snoozing underwater for the first time. Motionless, they lie on their sides or bellies with their eyes and nostrils closed.

"Until now, we thought that they slept only on land, in remote, inaccessible marine caves," says Alexandros Karamanlidis from MOm/The Hellenic Society for the Study and Protection of the Monk Seal in Athens, Greece.

The discovery could help better protect the endangered species, of which only 700 remain in the wild. Conservation efforts should include coastal waters, as well as marine caves, the team says.

They report six separate observations of seals sleeping at sea from 2011 to 2016, across different Greek coastlines at depths of up to 7 metres. In one case, the seal slept on the water surface with its head submerged. After 3 minutes it lifted its head to breathe, still with its eyes closed.

Monk seals can hold their breath for up to 15 minutes, but may possibly sleep underwater for even longer by coming up for air without waking (*Aquatic Mammals*, DOI: 10.1578/AM.43.1.2017.82).

NASA/JPL-CALTECH/MSSS

The gases that kept Mars warm

A DASH of hydrogen or methane in the atmosphere could have kept Mars warm enough for water to flow.

Ever since the 1970s, we have known that chilly Mars must have once been warm enough for rivers. But we've struggled to explain how a world much farther from the sun than Earth is could get so warm.

Today, the thin Martian atmosphere is mostly carbon dioxide, and traps little heat.

Now Robin Wordsworth of Harvard University and his team have worked out that if just a few per cent of a mainly CO_2 atmosphere is made up of molecules of hydrogen or methane it could make all the difference. When these gases collide with CO_2, they absorb light at key wavelengths, so the planet retains enough heat for water to flow (arxiv.org/abs/1610.09697).

"It's really exciting," says James Kasting at Penn State University in University Park, whose team had previously calculated that much more hydrogen would have been needed.

"We had to wave our arms a lot to justify that much hydrogen in the atmosphere," Kasting says. "This new paper allows that same hypothesis to work with a lot less arm-waving."

Brush like a Genius

When Oral-B created Position Detection Technology combining motion sensor technology in the brush, and video recognition using a smartphone's camera, it created a high-tech toothbrush that takes oral hygiene to new levels.

FOR THE 7,500 P&G scientists around the world, coming to work is all about meeting a single challenge – how to bring science to life! Finding ways to take their scientific know-how and transform it into surprising, often deceptively simple solutions. Solutions that ultimately become "the secret science in your home" that make each day just a little bit better.

We can't say they didn't warn us. Dentists have cajoled and chided. Brush twice a day, gently. For at least two minutes. And don't miss any teeth. That's the best way to remove plaque without damaging teeth or gums. We the patients have nodded, promising that this time - this time! – we will take our brushing seriously. But after a few days, we're back to our old ways.

Changing brushing habits is easier said than done. In the UK and the US, people brush on average for 47 seconds, pressing up to five times too hard, according to extensive research by dental care leader P&G, creators of Oral-B. And 60 per cent of people neglect their molars. "Good brushing technique is something dentists find hard to teach," says Adam Boulding, a biochemist and toothbrush expert at Oral-B.

There's more at stake than dazzling smiles and fresh breath. Oral hygiene has a major impact on other aspects of health. The mouth is home to some 500 species of bacteria which produce acids that can damage teeth. They can also infect gums and even end up circulating in the blood where they cause other problems. Gum disease has been linked to diabetes, arthritis, heart disease and even premature birth. So finding a way to improve oral hygiene is important.

State-of-the-art brushing

It's a goal that Oral-B has pursued since it was founded by the US periodontist Dr Robert Hutson in 1949. The brand has always taken inspiration from the dental profession, starting with round-ended bristles and continued to innovate with breakthroughs such as bristles that fade as they wear and electric toothbrushes that oscillate at up to an amazing 8,800 times per minute. Yet even with state-of-the-art tools, many people struggle to perfect their brushing.

"For decades, we helped our consumers by making better brushes," says Boulding. "Now we've realised we need to help them understand how to brush better as well."

Small changes in technique can have a big impact on oral hygiene. For example, most people tend to favour one side of their mouth over the other and so do not brush all their teeth equally. "Dental professionals can tell instantly whether you're right or left-handed by looking into your mouth," says Frank Kressmann, an engineer and toothbrush designer with the company. People also brush on "auto-pilot" and so repeatedly miss the same mouth areas.

That's why Kressmann and his colleagues designed the Oral-B Genius 9000 toothbrush, which teaches people to brush more effectively. It works by sensing where in your mouth you've cleaned and shows you where you need to clean more (see Position Detection).

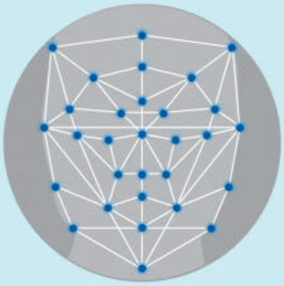
POSITION DETECTION

How can a toothbrush know which part of your mouth it's cleaning? "That was one of the toughest nuts to crack," says Frank Kressmann, the P&G engineer who developed the Oral-B Genius 9000. Somehow the brush has to know where it is in your mouth.

To solve this challenge, Kressmann and his team fitted the brush with a set of accelerometers that measure changes in motion in three dimensions and so calculate changes in brush angle of just a few degrees. That's just how smartphones detect whether they are vertical or horizontal.

But the angle of the brush doesn't reveal what part of the mouth the brush is in contact with. So P&G scientists partnered with the world-renowned Fraunhofer Society for the Advancement of Applied Research to develop an app that users download to their smartphone. The app uses a phone's camera and facial recognition technology to measure the position of the brush relative to the mouth. Oral-B calls this Position Detection Technology.

For users, the technology is simple. They place the phone in front of them when they brush, perhaps attached to the bathroom mirror using the suction cup holder that comes with the Oral-B Genius 9000. The app then shows which parts of the mouth have been brushed sufficiently and which areas still need more work. "It's almost like having your dentist in your bathroom with you," says Kressmann.



Using the smartphone camera, the app detects the relative positions of the user's hand and face using image recognition algorithms

Motion sensors in the brush measure the orientation of the handle and send the results via Bluetooth to the smartphone

Finally, the app merges both information streams together to show which areas of the mouth have been cleaned and those that need more brushing

It combines this with all the features you'd expect from an advanced Oral-B toothbrush: a massage feature to stimulate the gums, a slower mode for sensitive mouths and even a tongue cleaning mode. The brush also senses the pressure it exerts and slows or even stops the pulsation of the brush head if this is too intense. And it has new lithium batteries that last up to 14 days so there is no need to take a charger on holiday. All this gives the brush the ability to remove twice the amount of plaque as a manual one and overcome some of our individual "bad" habits.

The design of the Oral-B Genius 9000 is based on a deep understanding of what we should do to clean our teeth in the best possible way and on expert advice from dentists. These experts requested the ability to remind patients to hit certain areas (those pesky molars on your weaker side, for instance). So the smartphone app that links to the brush can be programmed by your dental professional to issue encouraging notes and reminders during and after a brushing session.

> **"The brush sees, it senses where you've cleaned and shows you where to clean more"**

Game on

Oral-B also draws on elements of psychology to help people brush more thoroughly. Kressmann says that the team worked with a games designer to understand that people experience a kind of joy associated with purification and the team exploit that in the Genius 9000 app. "We've used the toolbox of gamification," says Kressmann.

When a user starts to brush, the app displays a circle in six blue segments corresponding to the six areas of the mouth. As the user brushes each area, the blue fades, leaving a clean, white segment. This, says Kressmann, taps into the joy of purification. The video game Pac-Man™, which involves cleansing a maze of dots, appeals in a similar way, he says.

Rewards for achievements also feature heavily. The Genius app offers badges for virtuous behaviours such as brushing regularly. If the brush cannot connect to the app, it remembers your last 30 brushing sessions and uploads that data when next connected. This allows users to track brushing habits over time.

But does this approach work? Data for the Oral-B Genius 9000 shows that users brush for 2 minutes and 24 seconds on average. That's even more than the recommended time of two minutes twice a day. "You don't concentrate on the time but on the areas of the mouth," says Egle Kiiver, a product researcher at Oral-B.

That's a significant change that could deliver big breakthroughs in individual oral health. Oral-B has long been the gold standard for at-home oral hygiene. With its dentist-inspired design, its electric toothbrushes can remove 100 per cent more plaque than a manual brush. "It's all about surprising amounts of science applied in deceptively simple ways - that helps us to break bad habits," says Boulding, "and form new good ones." ■

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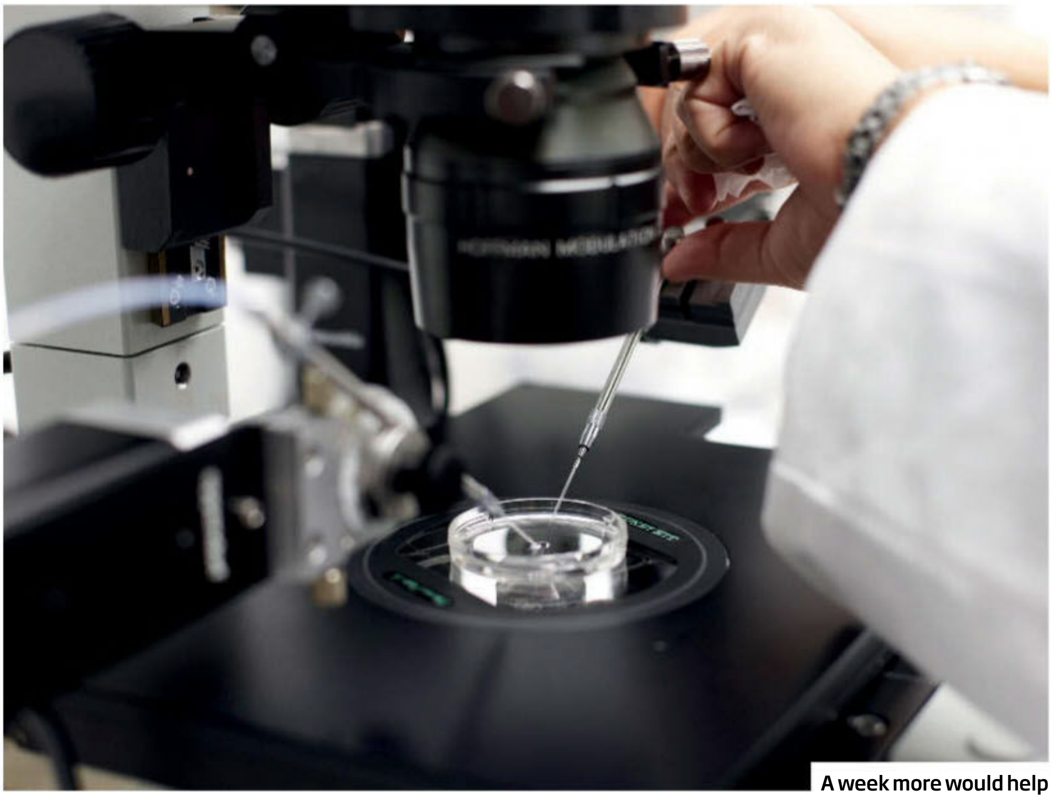

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A week more would help

The limits to growth

We should relax rules that stop research on human embryos at 14 days, says **Sam Wong**, as there is much more we can learn

WHEN it comes to studying our earliest existence, how far are we willing to go? Growing human embryos in the lab beyond the seventh day after fertilisation – the moment when embryos normally implant in the wall of the uterus – has been a long-standing challenge for biologists, but the latest research is allowing us to extend past that.

Earlier this year, a team led by Ali Brivanlou at Rockefeller University, New York, and another group at the University of Cambridge managed to keep embryos alive for longer than seven days, but they stopped the experiments two weeks in.

It's not that the embryos perished. Guidelines set by national medical societies in the US prohibit growing embryos in the lab for more than 14 days. In the UK and 11 other countries, that limit is enshrined in legislation, and embryos must be destroyed before they develop further.

Until now, this restriction wasn't an issue, but as science has caught up with the law, many researchers are eager to revisit the rule. Clearly, experimenting on well-developed embryos (or fetuses, past the 12th week from conception) would be ethically unacceptable to almost everyone, but that doesn't mean we shouldn't go beyond the first two weeks. The question is, how far, and to what end?

Magdalena Zernicka-Goetz, who led the Cambridge group, wants to open the "black box" surrounding this period of our lives. "It's one of the most critical phases of our early development and we don't know anything about it," she says. By extending the limit we could learn why many pregnancies are lost in the early stages, for example, and improve the current one-in-three success rate of IVF.

> **"It's one of the most critical phases of our early development and we don't know anything about it"**

At present, our understanding is limited by growing embryos in the lab only up to day 14. Brivanlou's and Zernicka-Goetz's embryos are not organised exactly like human embryos that attach to the uterus, in part because they grow in a flat environment. "The next stage is to be able to grow these embryos in a more three-dimensional structure," says Janet Rossant, a developmental biologist at the Hospital for Sick Children in Toronto, Canada.

Brivanlou argues that many genetic and neurodegenerative diseases start early in embryonic development. Observing how organs grow naturally might let us cure these diseases, or make new organs from scratch, he says.

So there is much to be gained from revising the 14-day limit, given its origins are more pragmatic than scientific. Little was known about the timing of human development when the rule was first proposed in 1979, though studies of other animals hinted at its importance (see "Baby steps", right).

After two weeks, a feature called the primitive streak appears in the embryo, the first indication of bilateral symmetry. And before this point, two embryos can fuse into one, or one embryo can split to form identical twins. Because of this, policymakers argued that an embryo cannot be considered an individual person before 14 days.

But this limit was not supposed to be philosophical. The Warnock Committee, which advised the UK government on human embryology in 1984, noted that "biologically there is no one single identifiable stage in the development of the embryo beyond which the in vitro embryo should not be kept alive".

Nevertheless, the committee felt a time limit was appropriate, "in order to allay public anxiety". By drawing the line at 14 days, policymakers in the UK and US hoped to permit research while showing respect for those with strong views about when life begins.

Jonathan Montgomery, chair of the UK's Nuffield Council on Bioethics, says although the limit was passed into British law in 1990, it's still fair to question it. "We shouldn't think that somehow 14 days was a line at which Parliament had previously decided the embryo was sacrosanct," he says. If scientists make a strong enough case for revisiting it, Parliament could consider changing the law.

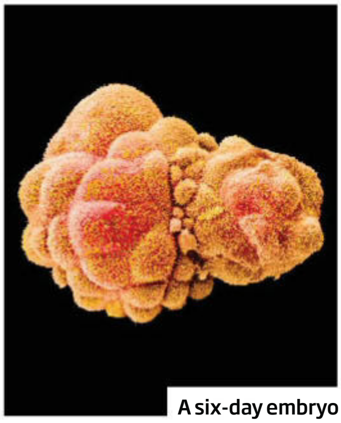
Beyond the limit

Discussion among researchers is well under way. Earlier this month, Harvard Law School hosted a conference on the future scope of the 14-day rule, and another meeting will discuss the rule in London in December.

One of the speakers at the Harvard meeting, Insoo Hyun, a bioethicist at Case Western Reserve University in Cleveland, Ohio, says there may be no need to extend the limit just yet. "They're just starting getting up to this time point," he says. "There's still so much more to learn about day 13, for example."

More urgently, grey areas need to be clarified on the fringes of the rule. Brivanlou's group has shown that human embryonic stem cells can grow into structures that resemble post-implantation embryos. These could be a useful model for studying early development, but no one is sure if the rule applies to them.

It might be too soon to shift the 14-day line, but it's worth beginning the conversation, says Rossant. "There are lots of inputs that need to be considered, ethical, legal, societal, as well as the scientific."


A six-day embryo

For those who believe life begins at conception, any research on embryos is unacceptable. "I think the basic question still comes down to what sort of moral worth do we want to give to various human beings," says Kevin Fitzgerald, a geneticist at Georgetown University, Washington DC, who is also a Jesuit priest.

David DeGrazia, a bioethicist at George Washington University in Washington DC, thinks the current rule is overly accommodating of those holding strong beliefs on when life begins. By comparison, abortion law is much less accommodating of conservative views, he says.

> "This is not a decision for scientists, it's a decision we must make as humans"

If not 14 days, where else could we draw the line? From a philosophical point of view, the crucial matter for moral status is sentience, and the capacity to have feelings, says DeGrazia. That comes much later, perhaps early in the third trimester – far beyond the stage we can imagine embryos reaching in the lab, and what many people would be comfortable with.

So a more realistic suggestion is a smaller change, such as a three-week limit. After that, the precursors of vital organs become identifiable, including beating heart cells and the beginnings of the central nervous system.

Setting the limit at this stage would allow the current trajectory of research to continue, without ruffling too many feathers. "If you can do all the science you want without alienating people with moral concerns so that they're firebombing clinics, it's good politics, and it's respectful," says DeGrazia.

Hyun argues that we shouldn't swap the 14-day rule for another arbitrary line in the sand, given we might wish to cross it in future. "Rather than one rule for all research across the board, it needs to be more nuanced," he says. "We have to look at real specifics about what the research is trying to do and if there's no other way to answer that question."

The political reality is that there must be a cut-off point to reassure the public that the research is being tightly regulated. "I strongly think it's important to have boundaries beyond which we cannot go," says Zernicka-Goetz.

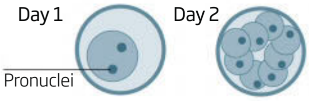
She and Brivanlou hope the limit will be extended by one or two weeks, but both are adamant that people of all backgrounds and cultures should have their views heard. "This is not a decision for scientists," says Brivanlou. "It's a decision we must make as humans." ■

Baby steps

Current regulations prevent studying human embryos in the lab beyond 14 days after fertilisation but animal studies of later stages suggest there is much more to be learned about human development

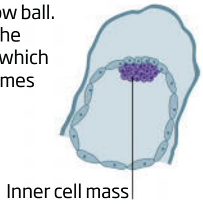
Day 1-2

Embryo begins as a single cell, the fertilised egg then divides to become two cells, then four, and so on



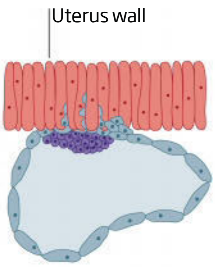
Day 5-6

Becomes a hollow ball. One side holds the inner cell mass, which eventually becomes the fetus



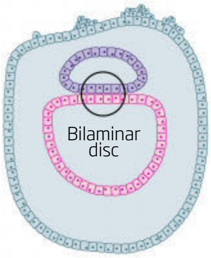
Day 7

Begins attaching to uterus wall



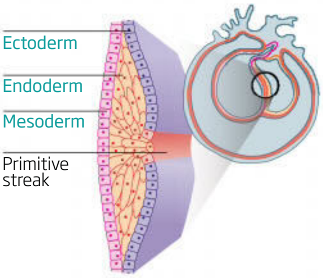
Day 12

Second cavity forms within inner cell mass, creating a disc in which features of the embryo will appear



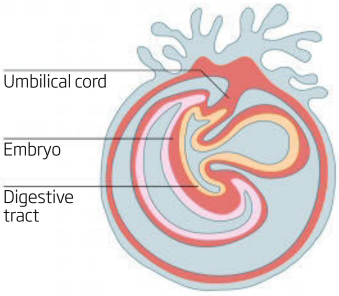
Day 14-21

The primitive streak, the first sign of bilateral symmetry, appears in the disc. The embryo splits into three layers and forms precursors to the nervous system and heart



Day 22-28

The heart tube starts contracting. The neural tube forms the beginnings of the brain. Limb buds and precursors of other organs appear



Flight of fancy?

Speculation about the EM drive, a proposed physics-busting starship engine, is back but is it still just for dreamers, wonders **Geraint Lewis**

FROM Earth, light takes four years to reach Proxima Centauri, the nearest star to our sun.

Compared with light, our most powerful rockets are sluggish, and journeys between the stars seem doomed to involve thousands of years of sliding through the blackness. The growth of any Galactic Empire appears destined to be a slow and sedate affair.

So, are dreams of an empire just that, dreams? Not if you listen to the media, as reports of the advent of warp drives and strange electromagnetic (EM) propulsion bubble at the edge of scientific inquiry. These would unshackle us from the need for vast fuel loads and offer rapid journeys to the stars. All we need to do is relax the laws of physics.

But to most scientists, these laws are not for bending, let alone breaking. As a result, suspicious eyes must be cast over the most recent claims, including from within NASA, of metallic cavities in which microwaves rattle around and produce directional thrust: the EM drive. This could give years of non-stop propulsion. All that's required is to disregard Newton's rules about action and reaction. It isn't the first time such talk has caused a stir.

Why can't the proven physics of our rockets get us to the stars? The problem is that you have to lug fuel with you. Look at Saturn V, one of the most powerful rockets ever built. It's really just a device for hauling fuel into space and landing a pair of astronauts and a few tonnes of metal on the moon, a paltry 1.25 light seconds away. And it is slow. Journeys to the stars could be speeded up by using a rocket that fires continually, but prohibitive quantities of fuel would be needed. Rocketry, as we know it, is a dead end for this.

Medical intervention

Doctors could be potent allies in the push to end the war on drugs, says **Danny Kushlick**

THE issue of legalising and regulating drugs has at last become a serious subject for debate among medics in the UK.

The reason? A passionate editorial in London-based medical journal *The BMJ* that urges doctors to "use their authority to lead calls for pragmatic reform informed by science and ethics". It follows calls by the UK's Royal Society for Public Health and Faculty of Public Health to decriminalise personal possession of drugs.

Such interventions are welcome in an area still treated as taboo by many senior UK politicians, who refuse to consider reform despite the country having a dire rate of drug-related deaths.

So what is the place of medics in campaigning for reform?

Harm-reduction services in response to the emergence of HIV are a great example of a health lobby achieving a substantial shift in policy that saved tens of thousands of lives. This pushed then UK prime minister Margaret Thatcher to fund provisions, such as needle exchanges and free condoms, that reduced HIV levels to among the lowest in the world.

At the same time, though, the UK has continued the war on drugs to such an extent that its excellence in harm reduction is fundamentally compromised. It is the government's dirty little secret: some of the harms that it works to minimise are the very ones that criminalisation causes, a factor that it has historically failed to acknowledge.

> **"It will be ever harder for the government to trot out its mantra about drug use falling and all being well"**

A fatal "code of silence" shared by professionals and politicians is finally being broken, and it will be ever harder for the government to trot out its oft-repeated mantra about drug use falling and all being well in prohibition land.

All is not well – and, in the absence of political leadership, No wonder speculation goes on about other ways of making such journeys. The press is abuzz with plans for tiny wafersats to sail to Proxima Centauri on laser beams. But a wafersat can't carry people. True starships are required.

And here we are stuck. Science offers some interesting ideas, such as the theoretical Alcubierre drive, which suggests that if we can just bend space and time the right way, we could outpace light across the universe, while keeping Einstein's relativity happy. But to build this drive, we would have to master forms of matter and energy we don't know even exist.

While the media feed on EM drive-like stories, the science is out in the cold. Hype masks the lack of experimental results and theoretical justification in journals, the lifeblood of scientific debate. This leaves most scientists thinking there is little behind the smoke and mirrors.

And for those who are not scientists, but who dream of interstellar flight and galactic colonisation, and wonder what to make of all of this, remember the old adage: "If it sounds too good to be true, it probably is." ■

Geraint Lewis is a professor of astrophysics at the University of Sydney, Australia

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health bodies are rising to the challenge and raising the alarm. But reform will require sustained and growing pressure, and we look forward to seeing members of the royal colleges – professional bodies for various medical specialities in the UK – also joining the campaign for change.

Ultimately, health professionals need to assert their rightful place at the head of national and international drug policy, with science and medical ethics as their trump cards. ■

Danny Kushlick is founder of the Transform Drug Policy Foundation, a charitable UK think tank

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INSIGHT Gene editing

NG HAN GUAN/AFP/GETTY

Ethical concerns flagged up

Will the US and China face off over CRISPR?

Sally Adee

THE first human test of the gene-editing technique CRISPR has taken place at West China Hospital in Chengdu, where oncologists used it to treat a man with lung cancer.

Similar trials are expected to start in early 2017 in the US, sparking speculation that the two countries are embarking on a "Sputnik 2.0"-style space race for genetic manipulation. But is this a responsible way to frame the development of a technology that is so fraught with possible risk?

The Chinese trial involved collecting the man's immune cells, editing them using CRISPR to make them much more aggressive and reinjecting them to fight the cancer cells.

Such use is fairly uncontroversial because the alterations have no bearing on the reproductive system, so the interventions can't be inherited.

But other proposals, such as eradicating rare genetic diseases, would introduce changes that can survive down the generations. The endgame with these is more radical.

Take the Human Genome Project-Write, which aims to build an artificial human genome. At its launch earlier this year, one of its founders, George Church, described a future in which we could wipe out diseases and adapt our species to the modern environment.

Figuring out how will require genetic tinkering, and that's where ethicists come in. China has already performed CRISPR edits on embryos four times. Here, the US lags behind.

"Fighting disease has no national boundaries. If groups in China find cures, we all benefit"

Which brings us back to that space race comment: speaking to *Nature*, which revealed the Chinese trial last week, Carl June at the University of Pennsylvania described a coming "biomedical duel on progress between China and the United States".

The winning nation may be the one that first relaxes its gene-editing rules. CRISPR is already being used in the US and elsewhere to create pigs that are immune to many diseases, cattle that don't get TB and chickens that resist bird flu. But the US Food and Drug Administration isn't on board yet, keeping these strictly in the lab.

If it's tough to get the FDA on side, it will be even harder to get backing for human clinical trials. Although the US has no official ban on CRISPR, it prohibits federal funding for research involving human embryos, and regulatory approval is needed for human gene editing.

And that's where some ethicists have a concern. "The space race is a terrible metaphor," says Hank Greely at Stanford University. "Fighting disease has no national boundaries. If groups in China – or Mexico, or Indonesia, or Russia – find cures, we all benefit."

He sees darker implications in the metaphor. "It seems to me a crude effort to create excitement, hype, more funding," he says, "and perhaps laxer controls."

In the West, it's widely assumed that China's regulations benefit from a more-relaxed view of ethics, particularly in gene-editing research. It's less clear whether this reflects reality or Western prejudices.

"The extent of enforcement is unclear but that's true here also to some extent," says Greely. He doubts the differences are major, but cynical people in the US could use such claims to convince regulators to loosen rules.

"One might dismiss the space-race talk as hyperbole business as usual," says Greely, "but its aim at China makes it a bit more dangerous than that in an era when there are people in the US who want to demonise China." ■

Roboshop

Artificial intelligence and robotics are revolutionising business. And leading the way is the online grocery store Ocado

IN THE control room at Ocado's automated warehouse in Hatfield, 50 kilometres north of London, the firm's head of research is wielding something rather odd: an Xbox game controller. But Alex Harvey is not about to zap some aliens. Instead, with a deft twitch of his thumb, he zooms into a 3D computer model that looks, at first glance, like some kind of bizarre, multilayered train set.

But this is actually an animated, real-time visualisation of the thicket of over 30 kilometres of conveyor systems in a warehouse the size of eleven football fields. It models the movement of thousands of crates around the conveyor belts to workstations where just a few human workers pack them to fulfil hundreds of thousands of online grocery orders every week.

This simulation is crucial in designing the plant and testing the algorithms and software that controls it. And it also helps troubleshoot problems: if a crate jams, operators zoom in to see what's gone awry. "The number of products picked per hour in a plant this size is so high that any minutes lost really matter," says Harvey.

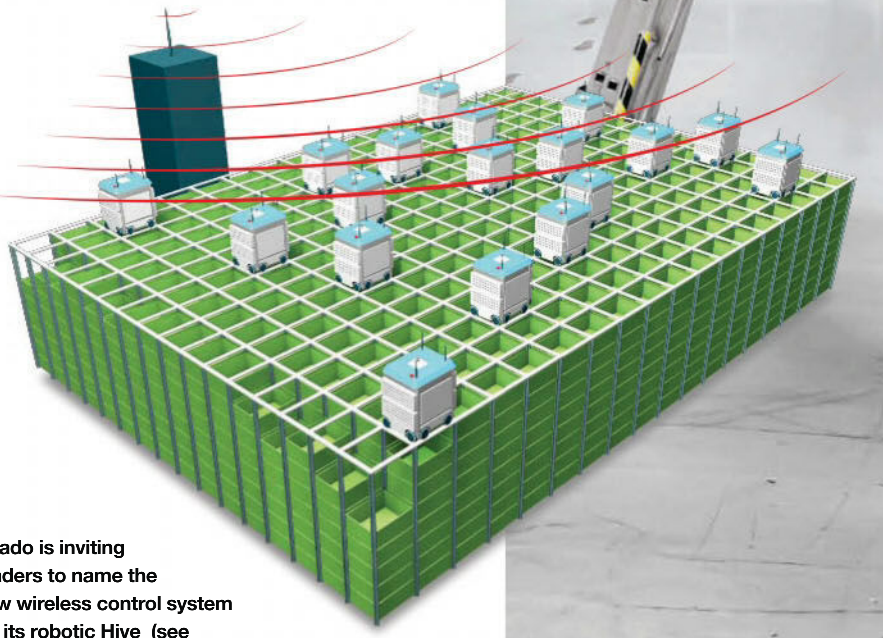
That's important to Ocado, which promises to deliver shopping to customers' homes within a one hour window of their choosing. In a business that's sending over 3 million items to UK homes every day, shaving a tenth of a second off the picking process can create a huge competitive advantage. "We're chasing down fractional improvements," adds Harvey.

And what is invisibly delivering most of those gains? Artificial intelligence and machine learning systems that can spot patterns in masses of data and bring into focus otherwise hard-to-fathom relationships between inputs and outputs.

So, what exactly can be optimised by AI in an online grocery warehouse? Plenty, says Harvey, starting with the routes that pallets of goods - potatoes, baked beans, and so on - take once they have entered the warehouse. Each warehouse has an inbound side where trucks bring in groceries from suppliers, and an outbound side where crates full of shopping bags are dispatched to customers' homes.

There are various routes each item can take on this journey. And with more than 48,000 different products, more than any conventional UK supermarket, and hundreds of junctions, there is a truly astronomical number of different routes through this warehouse. The question is how to route them all in a way that maximises throughput. That's where AI steps in, says Harvey.

"We use machine learning throughout the business to optimise everything from the format of the online shop to the conveyor routing, how we lay out the warehouse, which goods appear where and when - right down to the amount of dry ice we put in the frozen food boxes," says Harvey. And it has to be



Ocado is inviting readers to name the new wireless control system for its robotic Hive (see Competition box)

The SecondHands robot will help human engineers maintain Ocado's warehouses

adaptive too - to seasonal changes in food demand, for instance.

It all amounts to an ambitious use of AI. But Ocado is already planning to replace its current warehouse format with an even more advanced robotic one (see diagram). This brave new future is already taking shape in two plants in southern England.

Instead of using complicated arrays of conveyors to bring grocery items to pickers, thousands of wirelessly-communicating robots will collect items from a vast grid - up to three times the size of a football pitch. Each cell in this grid contains a stack of crated groceries. Once a robot has plucked, say, a crate of cucumbers, it will travel to the edge of the grid and pass it to a human or robotic picker. Then another robot arrives and offers the picker cabbages and so on until the customer's order is completed. As this grid is akin to the honey cells in a beehive, Ocado calls this new format the Hive.

In the Hive, AI becomes even more crucial. It must manage the 2D optimisation of robot movement on top of the Hive, the 3D problem of crate storage within the Hive and the 4D optimisation problem of how all this changes over time.

All this is part of what the company calls the Ocado Smart Platform, or OSP, which it sells as a package to other retailers. The OSP includes an e-commerce website, a Hive-like warehouse and the ability to plan deliveries with Ocado-like accuracy and reliability.

And Ocado is involved in other ground-breaking robotics projects too, says robotics research team leader Graham Deacon. His team is part of two projects funded by the EU's Horizon 2020 science fund. The SecondHands project is developing a humanoid robot to help human technicians maintain warehouses by handing them tools and even holding ladders. And the SoMa project is developing manipulators capable of handling fragile goods like soft fruit.

The company hopes to have the robot helpers working within five years. But Paul Clarke, Ocado's chief technology officer, has even more ambitious goals: "We intend to pepper the planet with these warehouses for ourselves and our OSP customers," says Clarke. "And that means developing robots not only to help maintain these facilities but one day, even to automate their construction too." ■

More at: www.ocadotechnology.com

Competition:
Win a £100 Ocado shop delivered to your door

In Ocado's warehouses of the near future, thousands of robots will pick goods and pack cartons for delivery to customers all over the UK (see diagram). But controlling all these machines accurately in a vast area is tricky. So Ocado and the technology company Cambridge Consultants have developed an entirely new wireless system that can communicate with each robot up to 10 times a second and could scale to even larger operations.

The new system uses 4G telecoms technology and broadcasts in the same 5GHz part of the radio spectrum used by Wi-Fi. Ocado says this kind of coordination is a key building block in automating everything from warehouses and factories to building sites and airfields.

Now Ocado is asking readers to suggest a name for its robot communication system.

The best idea will be rewarded with £100 of Ocado shopping delivered to their home at a time of their choice (or an equivalent prize).

The competition closes on 31 December 2016 with the winner announced early next year. To enter the competition and to see the terms and conditions, go to: ***newscientist.com/ocado***

MATT MCCLAIN/THE WASHINGTON POST VIA GETTY

Time to take stock?

Burst the filter bubble

Facebook is under fire for trapping users in filter bubbles that reflect only their own views. **Sally Adee** asks what we can do to break free

IN THE wake of the US election, concerns are surfacing over the filter bubbles that mediate the information people see in their social media feeds.

Filter bubbles are formed by the algorithms social media sites like Facebook use to decide what information to show you, based largely on your own tastes. The idea is to keep you engaged, but the result may be a world view skewed to fit your own preferences and biases. With 62 per cent of Americans getting their news from social media at least once in a while, the fear is that filter bubbles could affect how you make decisions in real life.

"If this window is filled with highly partisan and, in some cases, false news, then many people will be assessing political candidates and information on the basis of distorted and misleading information," says Martin Moore at King's College London.

So what can social media sites – and their users – do to burst these bubbles?

You can take control of your own feed. You don't need to go to extremes, says Philip Howard at the Oxford Internet Institute, UK – there's no value in wading into the fever swamps of white nationalism or climate denialism, for example. But equally don't unfriend people just because they didn't vote like you.

"Your context is shaped by who you friend and unfriend," he says. "Every time you tailor your feed to get rid of people whose opinions you don't like, you add more boundaries to your reality."

People who support defeated political parties, he says, are particularly vulnerable, as their bubbles may shrink further if they retreat into like-minded safety.

How to break out? It isn't easy. Network effects reward extremists and drown out moderate views, says Cesar Hidalgo at the Massachusetts Institute of Technology. The problem is not just the extremists on the other side of the political spectrum, but those on your own. "If you say something moderate, you might get chewed out," he says. "Social network filter bubbles create an environment in which moderates have incentives not to speak. There's a lot of enforcing going on."

The filter bubble phenomenon is largely a design problem, says Hidalgo. Facebook and Google have already restricted advertising on fake news sites, but this doesn't stop users sharing false information, and bubbles are made of more than just falsified news reports.

> **"Tailoring your feed to get rid of people you don't like adds more boundaries to your reality"**

Hidalgo has other suggestions. Facebook, he says, ought to design a "flip feed" button. Its algorithms could identify your bias, then show you stories selected from the other end of the political spectrum. An alert could pop up when an algorithm detects that your feed is getting too closed off and suggest people or pages to follow to widen your perspective.

Social networks might also introduce random, high-quality news stories into feeds, he says, or a Rotten Tomatoes-style reputation meter – an icon placed near the like button that could crowdsource people's ratings on a story's trustworthiness. Even if people manipulated it by scoring stories highly if they fit their

FAKE NEWS, FAKE VIEWS, FAKE PEOPLE

It's not just your opinionated friends who skew your filter bubble (see main story). On Twitter, automated bots add to the noise.

In a new study, Philip Howard and his colleagues at the Oxford Internet Institute scoured 19.4 million tweets between 1 and 9 November, in the run-up to the US election. They found that 20 to 25 per cent of election-related traffic came from accounts that were probably bots.

The top 20 accounts averaged over 1300 tweets a day, generating a total of more than 234,000 tweets over the period. These bots largely worked to spread pro-Trump messages. By election day, pro-Trump bots were tweeting five times as often as pro-Clinton bots.

confirmation bias, the button may serve as a reminder that not everything you read on the internet is true – something that's easily overlooked in the rush to confirm your beliefs. "Unfortunately, we still have the problem of over-believing things," says Hidalgo.

Howard says part of the problem is that all sources are presented in the same way, whether you're looking at *The New York Times* or your neighbour's blog. He thinks Facebook should divide and label content into news and other posts. That way, opinions and false information are not interpreted as legitimate news.

"It's time for us to treat Facebook as a media firm," he says. "They need to get a public editor and curate their content."

But Nathan Matias at MIT's Center for Civic Media thinks we should avoid giving social networks even more authority over our reality. "Do we really want them to have even more control over our online existence?" he says. "Do we actually want to give Facebook the power to decide what's true and what's false?"

There's another caveat. "We are still so early in our understanding of how social networks really work," Matias says. We don't know how much impact filter bubbles have on our views. In fact, the idea of the filter bubble has never been proved empirically.

In any case, Matias is sceptical about how useful bursting the bubbles would be. Filter bubbles don't only exist in social media, after all, and how far outside your own world view would you have to look to gain an unfiltered perspective – if such a thing were even possible?

In fact, maybe this new obsession with the filter bubble is itself viewed through a filter bubble. "In 2008, we celebrated when Obama used Facebook in creative ways to win the election," says Howard. ■

Chinese town uses your face as a ticket

WHO needs tickets when you have a face? The town of Wuzhen, a tourist attraction in eastern China, has started using face-recognition technology to identify people staying in its hotels and to act as their entry pass through its gates.

The system, which is expected to process 5000 visitors a day, has been created by web giant Baidu – often referred to as the "Chinese Google".

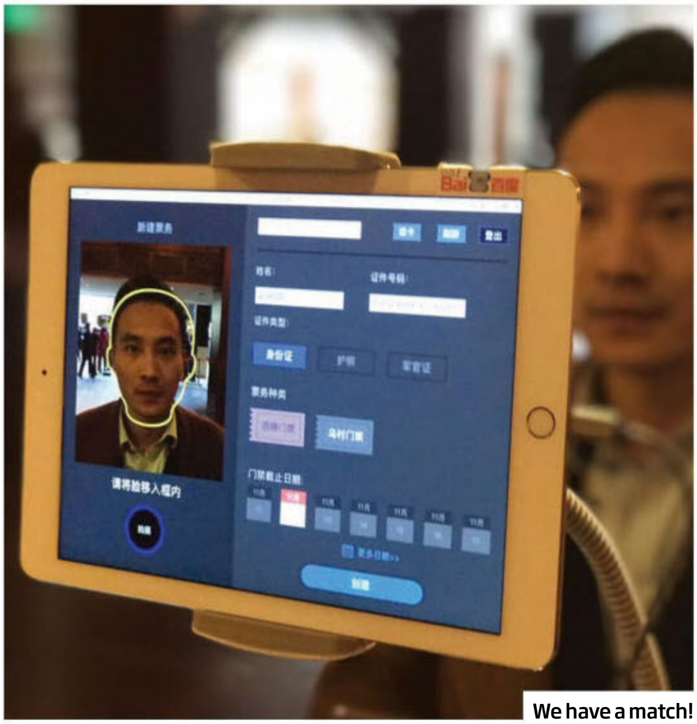
Wuzhen is a historic town that has been turned into a tourist attraction with museums, tours and crafts. When people check in to hotels in the area, their picture will now be taken and uploaded to a database. If they leave and re-enter the town, the face-recognition software will check they are a hotel guest before letting them back in.

Previously, multiple types of entry ticket had to be handed out to distinguish between one-off visitors and those staying for longer. But guests could easily play the system by sharing their tickets to avoid paying the entry fee.

To prevent this, the town started to use fingerprint identification for hotel guests. "But this took too long," says Yuanqing Lin, director of the Institute of Deep Learning at Baidu.

The new face-recognition system uses cameras to spot people as they approach a turnstile at the entrance. Faces are then checked against the database of registered visitors, all within a second. If you're in the database, you're allowed in; if not, the doors remain closed.

Baidu's face-recognition software uses neural networks – a technique modelled on the brain's ability to recognise complex patterns. The company has trained the software on huge data sets that together total more than 1 billion images of people's faces, and says the system has an accuracy of 99.8 per cent – although this was achieved by examining still images. The system at Wuzhen also detects facial movements, so can't be fooled by someone holding up an image of another person's face.



BAIDU

We have a match!

"It was only a matter of time before face-recognition software was rolled out on this scale," says Mark Nixon at the University of Southampton, UK. It's likely the technology will soon be seen elsewhere, he adds.

Some airports already have a form of face-recognition software at passport control, but the setup is different. At an airport, you present your passport and the software determines whether the person standing in front of the camera matches that identity. But at the gates of Wuzhen, tourists do not show any ID. Instead, the software searches its large database for their faces.

> "It was only a matter of time before face-recognition software was rolled out on this scale"

Compiling a database of faces in this way presents privacy concerns. Lin says the responsibility for storing the data falls to the Wuzhen attraction that uses it, not Baidu.

"In China, there is not a single overarching privacy law, but companies do have obligations to keep data safe," says Tiffany Li, an affiliate of the Center for Information Technology Policy at Princeton University.

Companies around the world are building large databases of personal information, with some starting to store biometric information such as fingerprints too. "This will make it easier to log on to your bank, but it will also be more of an issue if the database is hacked," says Li.

The Wuzhen system is currently being used for the 15 to 20 percent of visitors who stay in the town's hotels, but if the trial is successful, Baidu hopes to expand it and run similar systems elsewhere, such as at other tourist spots and theme parks. "We want our software to eventually be used by all of the town's visitors, and then in many other places around China," says Lin. Timothy Revell ■

Hot water engine

James Randerson explores turning waste hot water into electricity

WASTE not, want not... An engine that generates electricity from waste hot water could reduce energy consumption and carbon emissions for thousands of different businesses, from cargo shipping to data centres.

So says Exergyn, a firm based in Dublin, Ireland, which plans to run the first industrial trials of its technology next year.

Globally, Exergyn estimates that the heat lost in waste hot water from industrial processes amounts to around twice the energy in Saudi Arabia's annual oil and gas output.

"There's just so much waste hot water in the world," says Exergyn CEO Alan Healy. In most cases companies are actually spending energy to cool it.

Cargo ships, for example, typically pump waste hot water from the engine around the vessel to cool it down. And in data centres, electricity-hungry fans are used to dissipate the heat generated by rows of servers. Finding an efficient way to capture and use this wasted energy would both reduce costs and cut emissions.

The Exergyn Drive exploits the quirky properties of nitinol, an alloy of nickel and titanium. You can bend nitinol out of shape, but when heated it undergoes a phase transition and reverts to its original crystal lattice structure. This "shape memory" property makes nitinol desirable in a wide range of applications, including medical devices and sunglasses. And unlike most materials, nitinol expands when cooled, like water when it turns to ice.

> **"The Exergyn Drive can produce electricity more cheaply than gas or coal"**

These two properties drive the Exergyn engine. Inside the device, a bundle of metre-long nitinol wires are attached to a piston. Cold and hot water are alternately flushed over the wires, making them rapidly expand and contract by 4 centimetres, driving the piston up and down. A hydraulic system converts that linear motion into rotary motion, which in turn drives a generator. The engine produces 10 kilowatts of electricity from around 200 kW of thermal energy in the hot water.

That might not be hugely efficient, but this "free" energy would otherwise be wasted. And often, money and energy would be spent cooling the waste water.

The company is now planning tests in 2017 at Dublin Airport and two landfill sites. The Exergyn technology will produce electricity on-site using water at 90 °C or less from a gas engine at the airport and from biogas generators at the landfills.

John Blowes, a past president of the Institution of Diesel and Gas Turbine Engineers, agrees there is a massive range of applications, but only if the technology is cheap. "It comes down at the end of the day to commercial viability," he says.

Mike Langan, Exergyn's head of product management, says the combination of no fuel costs and mechanical simplicity keeps costs down. He says it can generate electricity at £40 per MWh – cheaper than gas and coal. ■

Free energy: going spare

RAFFI MAGHDESSIAN/GETTY

ONE PER CENT

Body talk

A new electronic tattoo listens to the sounds of the human body, including the heart and muscles. The sensor-laden skin patch could be used in medical monitoring, to detect irregular heartbeats, for example. Placed on the throat, it could also act as a human-machine interface by picking up the vibrations of your voice, even in noisy conditions. In one demonstration, people used it to play *Pac-Man* by voice control (*Science Advances*, doi.org/bs62).

> "The most extreme surveillance in the history of Western democracy"

Whistleblower **Edward Snowden** on the UK's Investigatory Powers Bill, which has now been passed by both Houses of Parliament and is expected to become law within weeks.

Read my lips

AI has learned to lip-read. A deep learning system designed by researchers at Google's DeepMind and the University of Oxford was trained on some 5000 hours of BBC news videos, totalling 118,116 sentences and 807,375 words. It performed more than twice as well as a human lip-reading professional on a previously unseen set of clips (*arXiv*: 1611.05358v1).

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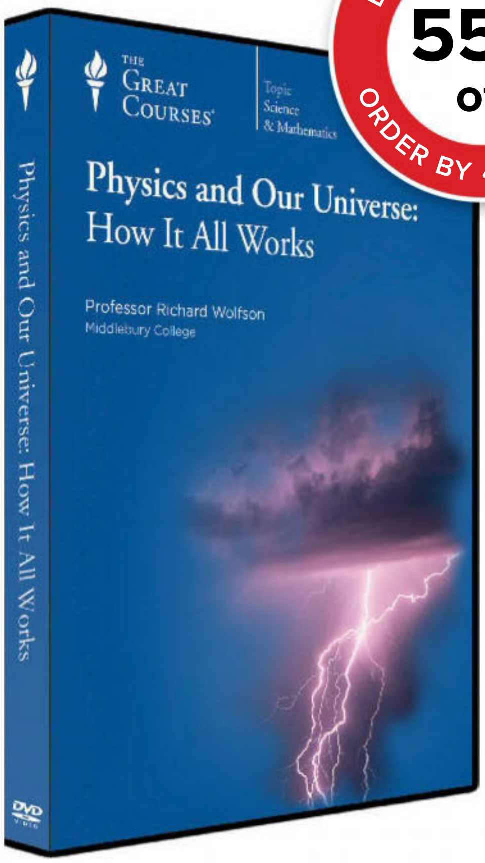
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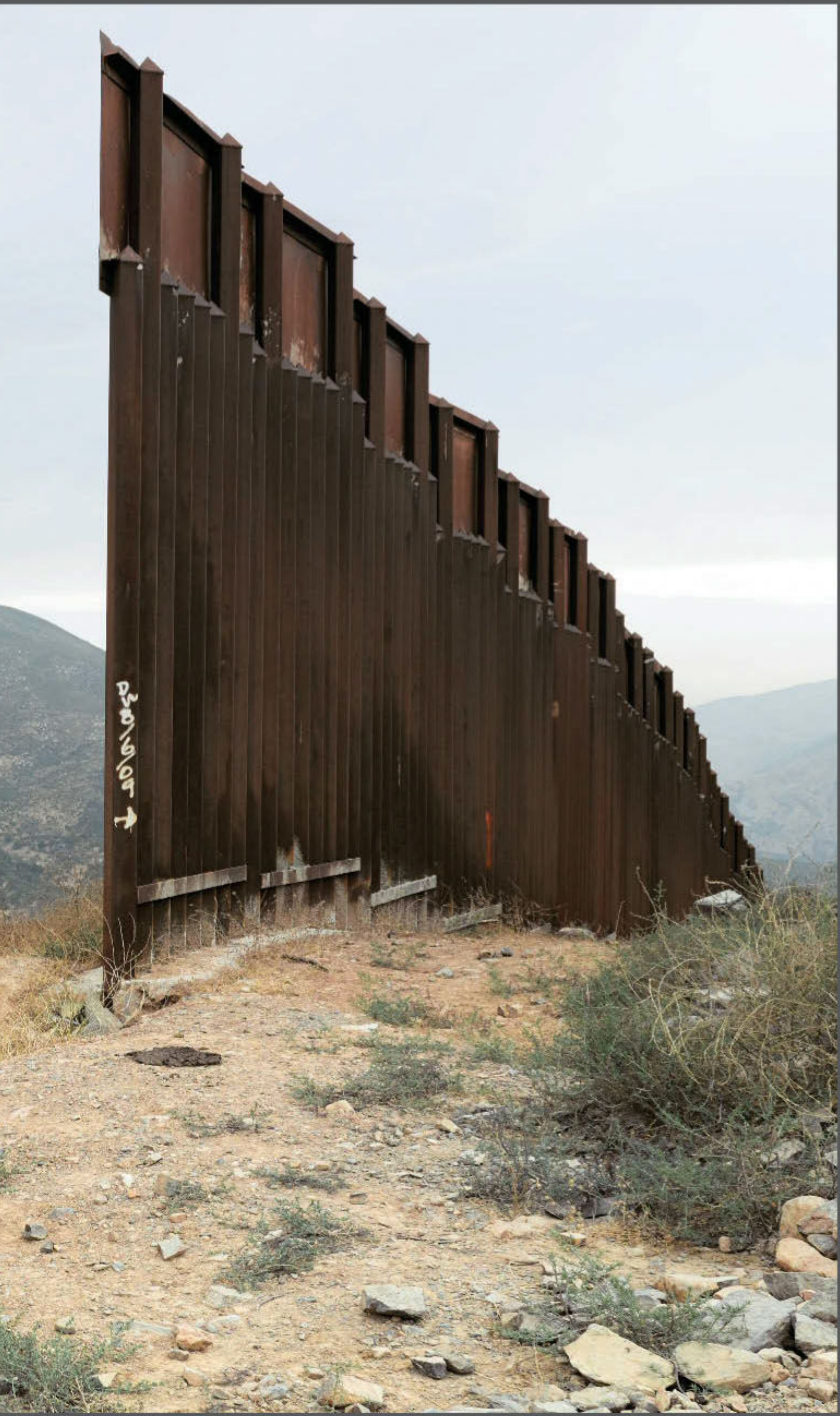


The invisible boundary

IN 1848, the U S and Mexico drew a line. The Guadalupe Hidalgo Treaty – and then the Gadsden Treaty a few years later – established an agreement about where the boundary between the two countries lay. Markers made out of stone, marble or iron were placed along the border, spaced a few kilometres apart.

Today, 276 of these obelisks dot the boundary, and thanks to Donald Trump, this strip is more contentious than ever. David Taylor, a photographer in Arizona, first saw one for himself years ago, on a drive out from his then hometown in New Mexico. "I was captivated by them," he says. "The monuments have been a witness to our changing national identity."

Taylor made it his mission to visit every single one. On and off over seven years, he explored the 690-mile stretch between the first obelisk near Mount Cristo Rey and the last at Playas de Tijuana. Each was slightly different. One obelisk might be sitting smack in the middle of a busy port of entry, covered in graffiti. Another might be found alone in the Chihuahuan desert, little changed since its installation in the 1800s.

In this photo (main image), you see Monument No. 250, located near Cañon del Padre beside a 5.5-metre-tall fence. Below is Monument No. 1 on the border of Texas and New Mexico, near the town of El Paso.

As for Trump's wall, Taylor is sceptical. "The border is not impermeable. The likelihood that the border is ever going to be impermeable is probably fantasy." Aviva Rutkin

Photographer

David Taylor

dtaylorphoto.com

A bit eccentric

From squashed electrons to self-destructing protons, careful scrutiny of everyday particles acting strangely can refresh our picture of reality, says **Lisa Grossman**

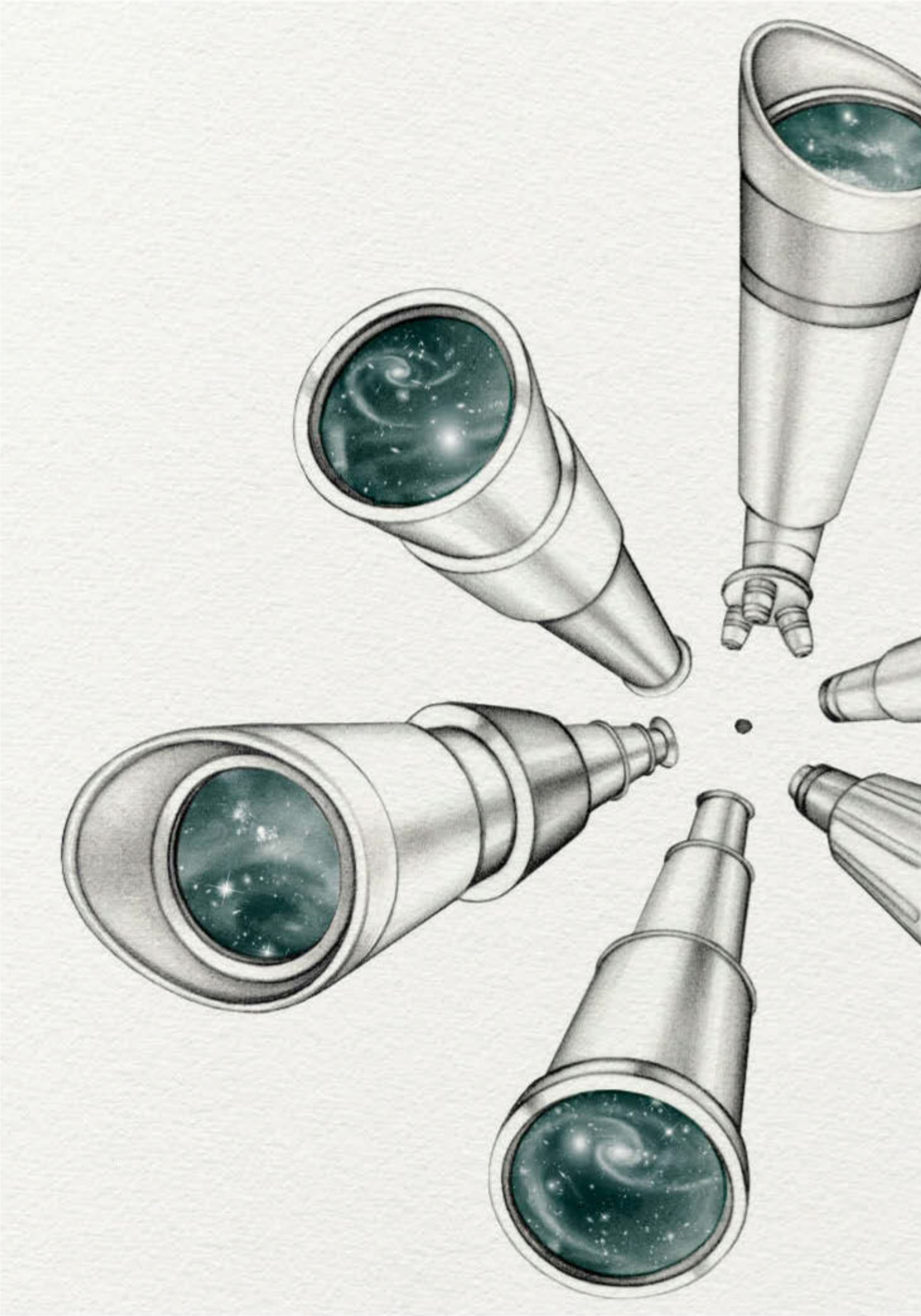
FOR a few heady months last year, the door to an unknown world was nudged ajar. An anomaly in data from the Large Hadron Collider, based at CERN near Geneva, Switzerland, indicated the presence of a peculiar new particle, a visitor so unexpected that it promised to transform our picture of how nature works. Then, with more data, the anomaly disappeared. The door creaked shut again.

It was a massive letdown. When the LHC found the Higgs boson in 2012, it marked the completion of the standard model, our best theory of matter and its workings. But there were no answers to the standard model's many mysteries: nothing new that might explain gravity, or the nature of the dark matter that dominates galaxies, or why particles such as the Higgs have the masses they do.

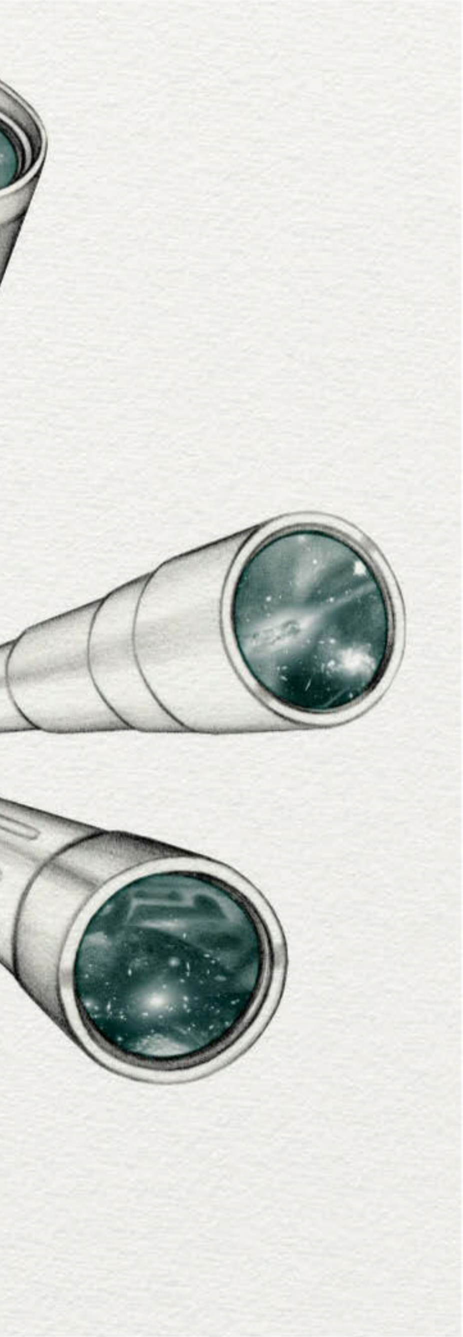
"The standard model is incomplete, so there must be something," says Lee Roberts, a particle physicist at Boston University. "But it seems like it's hard for them to see anything right now."

Pessimism is beginning to spread. A recent survey of 54 physicists at a workshop in Madrid revealed that 29 per cent of them think the LHC will not see anything new. Given that building an even bigger machine looks impractical, if not impossible, what now?

Go for precision, not power. That's the rationale behind a slew of experiments examining familiar particles for infinitesimal signs of deviant behaviour – weirdness that may betray the influence of new phenomena. It won't be easy. But by thinking small, the efforts described here might just beat the big beasts to the punch.



LAUREN MORTIMER



SHAPE-SHIFTING NEUTRINOS

Coy characters hint at hidden forces

Perhaps the most notorious known deviants from the standard model are neutrinos.

In the theory's original incarnation, these shy, shifty particles weren't supposed to have any mass. But in 1998, a 50,000-tonne tank of water under a mountain in Japan showed otherwise. Neutrinos come in three different "flavours" – electron, muon and tau – and the Super-Kamiokande detector caught muon neutrinos from the upper atmosphere morphing into the other two.

These "neutrino oscillations" are only possible if the three flavours have different masses – implying that they all do have mass, albeit tiny ones. The discovery earned the 2015 Nobel prize in physics. But while neutrino oscillations definitely point to something beyond the standard model, it's not clear what.

> **"Neutrino oscillations point to something beyond what we know, but what?"**

"There is more than one way to tweak the standard model to include it," says Ed Kearns at Boston University, a member of the Super-Kamiokande collaboration. "We are in the business now of putting together all the things we think we can measure about neutrinos and holding them up to the light to see if there's anything shining through a crack."

One possible ray of light would be if neutrinos and their antimatter siblings, antineutrinos, oscillate differently – that is, if they violate a rule known as CP symmetry.

Standard theories say that the big bang created an equal amount of matter and antimatter, and that the laws of physics treat both identically. This can't be absolutely true. Matter and antimatter destroy each other whenever they meet, so the fact that we live in a matter-dominated cosmos means CP symmetry must be violated in some way.

In fact, we know that the weak nuclear force, one of the four fundamental forces of nature, treats matter and antimatter differently – just not nearly enough to explain matter's dominance. That suggests some unknown force is responsible for the rest of the discrepancy. And because neutrinos are so shy of interacting through known forces, if they feel this new force it should be easier to spot.

Super-Kamiokande's water tank also detects neutrinos and antineutrinos that come from a particle accelerator in Tokai, Japan, 295 kilometres away. In July, this experiment, called T2K, saw signs that neutrinos oscillate differently from antineutrinos. "That's basically the definition of CP violation," Kearns says. "If it's there, you can seriously take into consideration that the neutrino sector is responsible for the matter-antimatter asymmetry of the universe."

The case is not closed yet, though. Out of the millions of muon neutrinos it has detected, T2K spotted 32 shifting into the electron flavour and just 4 muon antineutrinos doing the antimatter equivalent. That's not sufficient to say for sure that CP symmetry is violated. T2K is still gathering data and a similar experiment in the US, called NOvA, should help firm up the results.

There are other ways that neutrinos could show us new physics. The T2K result notwithstanding, they might surprise us by being their own antiparticles, a feature that would show up in a rare form of radioactive decay. Or there could prove to be a fourth, even more antisocial "sterile" neutrino, far heavier than anything the LHC can produce – and a strong candidate for dark matter.

ELECTRIC SQUEEZE

Inspecting the electron's flawless figure

Given we have poked and prodded them for so long, electrons and neutrons should hold no secrets. So any surprises these humdrum particles do hold would have big implications.

The standard model predicts they should be perfectly round. But any exotic unknown › particles could have some subtle effects on these ordinary ones, squishing or stretching them out of their spherical shape. Specifically, they would induce an electric dipole moment (EDM): a slight separation between positive and negative charges inside the particle.

"If you see an EDM, you know without a shadow of a doubt that that's new physics," says Brent Graner at the University of Washington in Seattle. That makes it an attractive target, particularly for budget-conscious physicists, because experiments searching for EDMs tend to be relatively small-scale and inexpensive.

The trick is to look very, very closely at a property called spin. Just as a spinning top wobbles slightly as it slows thanks to the torque applied by gravity, so a particle will wobble in an electric field – that is, if it has an EDM. The trouble is that any such wobble will be incredibly small and therefore ridiculously hard to spot.

> **"Imagine trying to spot a sliver 10 nanometres wide shaved off the top of Earth"**

Using supercooled thorium oxide molecules to amplify any deformations, the Advanced Cold Molecule Electron EDM experiment (ACME) at Harvard University has made the most precise measurement of the electron's spherical figure to date. In 2013, it found that any EDM these particles possess must be less than 10^{-28} electron charge centimetres, a measure of the distance between the positive and negative charges – that's a decimal point followed by 27 zeros before the 1.

David DeMille at Yale University, who works on ACME, puts it another way: if the electron were the size of Earth, its deviation from perfectly spherical must be equivalent to shaving a sliver less than 10 nanometres wide from the top and slapping it on the bottom. The team is now tweaking the experiment to increase that sensitivity.

Meanwhile, the nEDM experiment at Oak Ridge National Lab in Tennessee is probing neutrons. Previous experiments showed that the neutron is round to 1 part per trillion. nEDM is trying to improve that precision by another factor of 100 by embedding the experiment in superfluid helium. This will let the team increase the strength of the electric field acting on the neutrons and slow them down, boosting their chances of seeing a deformation – if there is one.

Over in Seattle, Graner's experiment is scrutinising the mercury atom. Others have even suggested trying to spot EDMs in protons to search for a hypothetical dark matter particle called the axion.

All these experiments are sensitive to the effects of particles that the LHC may not be capable of seeing directly. The LHC relies on smashing protons together, which briefly spawns other massive particles that can be identified by sifting through the debris. The higher the energy, the more massive the particles it can create. Even at its maximum design energy, however, the heaviest particles the LHC can find will be about 4 or 5 teraelectronvolts (TeV), says DeMille.

By contrast, with its current sensitivity, ACME would have sensed particles at 7 or 8 TeV, if they existed. The group's proposed improvements would push that limit, which should make it possible to see the influence of particles up 40 TeV. Further tweaks could feasibly get them as high as 100 TeV.

"By doing these very precise measurements, it's possible to be sensitive to the existence of certain kinds of new particles that have masses beyond the reach of any accelerator," says DeMille. "Certainly anything that's running now, but probably anything that's been conceived."

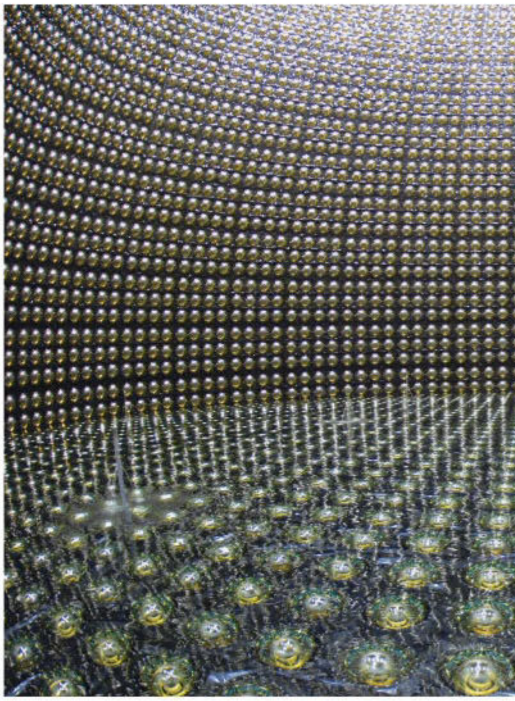
MAGNETIC MISBEHAVIOUR

The muon is preparing for its moment

The electron's lesser-known cousin, the muon, has been behaving badly for 15 years. Next year we might finally find out what's behind its disobedience.

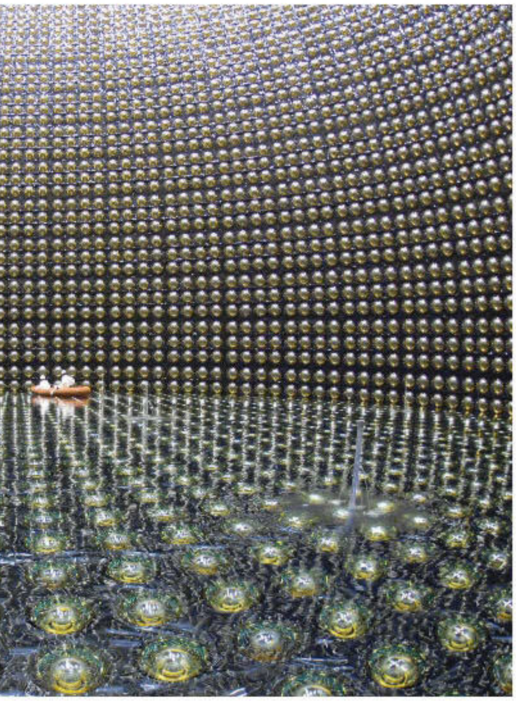
Both particles are essentially spinning balls of charge, so they generate a magnetic moment – to you and me, a north and south pole. In 1928, physicist Paul Dirac calculated that a quantity related to this magnetic moment, called the g-factor, should be exactly 2 for electrons and muons. But when we measured the electron's magnetic moment in the 1940s, it turned out to be slightly larger: more like 2.002.

DEAN MOUHTAROPOULOS/GETTY



We later discovered that was because so-called virtual particles, which constantly pop in and out of the vacuum according to the rules of quantum mechanics, nudge the electron's magnetic moment off-kilter. "It's like it has a dance partner that appears out of the vacuum, grabs its hand and spins it around," says Chris Polly at Fermilab in Batavia, Illinois – and the effect is even larger on the muon, which has 207 times the mass of its cousin. "Other particles seem to come out even more prolifically when they're around the muon." That makes it a particularly good candidate for finding the heavy particles predicted by a popular extension of the standard model called supersymmetry, which the LHC has so far failed to detect.

Most of the observed difference in magnetic moment comes from the influence of ordinary particles like electrons and positrons, plus a bit more from things that were unknown to Dirac but ended up forming the basis of the standard model: quarks, W and Z bosons and the Higgs boson. However, in 2001 theE821 experiment at Brookhaven National Laboratory in Upton, New York, showed that the muon's magnetic moment is more deviant, being roughly 1 part in 4 billion



KAMIOKA OBSERVATORY, ICRR (INSTITUTE FOR COSMIC RAY RESEARCH), THE UNIVERSITY OF TOKYO

bigger than it should be according to the standard model. The anomaly wasn't statistically significant enough to count as a discovery, and the experiment shut down before the team could get what they needed to make the result stick. But a new experiment called Muon g-2 ("gee minus-two") gives us another chance.

In 2013, the detector used in E821 – a gigantic ring of superconducting magnets 15 metres in diameter – was shipped on a barge from New York to Chicago (the picture below shows it in transit). There it will run again using Fermilab's muon beam. It should fire up sometime next spring, and if all goes well it will be taking high-quality data by next October. The physicists running the experiment hope that in 2018 they will be able to publish the first result verifying that Brookhaven was right.

For Polly, it's personal. He did his PhD research on the Brookhaven data, and has been Muon g-2's project manager since its inception. "I've been anxiously wondering whether that 15-year-old result was real or not, if it was something new and interesting," he says. "It's great for me to get to work on that here."

THE IMMORTAL PARTICLE

Protons never die – or do they?

The proton, that bedrock of the atomic nucleus, is supposed to be absolutely stable, meaning it never disintegrates. If it isn't, there must be some new force overseeing its demise. But no one has ever seen a proton fall apart – and it's not as if we haven't been looking.

That brings us back to the giant tub of water in the mountains of Japan. Although Super-Kamiokande is best known for its neutrino experiments, its detectors have been waiting for a proton to fall apart for the entirety of its 20-year run. It is looking for a particular kind of flash: unlike a neutrino strike, which sends a burst of blue light forward in the same direction it was travelling, a decaying proton would reveal itself in light beams shooting off in opposite directions.

"We have to sift through our data among things that are mostly going in one direction, and find things that are going back to back," says Kearns. "We're just waiting. We can't do anything to speed it up."

There are several different ways a proton could disintegrate, and each gives a different estimate for how long you might have to wait to see it happen. Super-Kamiokande's best limit on the one favoured by most physicists was published in 2014: once every 5.9×10^{33} years. That's 24 orders of magnitude greater than the lifetime of our universe, which has been around for 13 billion years – so we have no right to expect such an unlikely event to occur right when we happen to be watching.

> "No one has ever seen a proton fall apart, and it's not as if we haven't looked"

Then again, some "grand unified theories", which posit that all the forces merge into one at extremely high energies, suggest that the proton should live between 10^{30} and 10^{35} years – in which case there's a chance we might spot one dying among those passing through Super-Kamiokande . "It could be around the corner, it could be out of reach of even the next-generation experiment," Kearns says. "That's just what the universe has handed us."

SMASHING COMEBACK

Why the LHC could surprise us yet

The hunt for new physics on the "precision frontier", as physicists refer to their exquisitely sensitive tests, is full of promise. But as indirect experiments. which focus on the effects of new particles rather than trying to make them, they have drawbacks: for one, they can't tell you what that new physics is.

"That's the rub," says former LHC researcher Adam Gibson, now at Valparaiso University, Indiana. "If you make these things at colliders you have a better chance of telling what it is."

It may be too early to write off the LHC's chances. The collider recently restarted following a major upgrade in 2015, and has a way to go before it reaches its maximum design energy. So although the first run failed to turn up things theorists did expect, later runs could always find things they didn't. And even if not, the LHC itself will probably run precise tests on particles it can already detect to see if they continue to adhere to the standard model, says Gibson.

Wherever it shows, it would be strange if nothing new turns up, says DeMille. "Everyone believes there must be some new particles. It would be truly bizarre if there's not." ■

BROOKHAVEN NATIONAL LABORATORY.

The LHC has had much to toast (far left), but smaller, high-precision detectors like the one in Muon g-2 (left) and Super-Kamiokande (above) could be first to spot new physics

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Lisa Grossman is physics news editor at *New Scientist*

Breaking the pain cycle is going to take more than drugs, says **Jessica Hamzelou**

Hitting where it hurts

EMMA PAYNE'S day starts at 6 am, when the pain from her joints wakes her. She takes prescription painkillers and stays in bed until late morning, when they finally kick in, giving her a few hours of respite before the pain returns. "By 3 pm, all my joints hurt, whatever I've done," she says. The rest of the day passes in a cycle of ever-stronger painkillers, rounded off with sleeping pills. Payne has lived this way for the past two years, not only struggling with the pain but grieving for the active life she had before.

An estimated 10 million people in the UK and a fifth of the world's population has chronic pain, lasting 12 weeks or more. For many of them, treatments provide little relief. Even the strongest drugs often don't eliminate discomfort, and come with serious side effects. Not to mention they are addictive, make pain worse long-term and are all too easy to accidentally overdose on.

Now, though, researchers are starting to tackle the problem by rethinking the root causes of chronic pain. Rather than seeing it as a lingering version of the acute form, they have begun to recognise it as a complex disorder of the nervous system that changes the brain's structure, chemistry and activity. Such thinking could help dispel the myth that there is nothing wrong with those with chronic pain, and could lead to a new wave of treatments.

Part of the problem has been that most research into pain hasn't been asking the right questions. The majority of what we know so far is based on research into acute pain, says Marco Loggia at Harvard University.

When we experience an injury, the nervous system sends a pain signal to the spinal cord and the brain. The spinal cord provides the rapid reaction that makes you recoil from the source of the injury – a hot surface, for example. Your brain tells you you're in pain, and enlists a complex set of structures, including emotion and memory networks, to help you remember that pain for future reference.

In chronic pain, says Loggia, this system goes awry. The pain signal doesn't switch off, and the brain networks involved in pain start to change their activity, telling you you're at risk of injury when you're not. "Acute pain is mostly helpful, but chronic pain is not," says Loggia. While acute pain is like an alarm state, as it becomes chronic, the patterns of brain activity begin to change, he says.

Neuroimaging is starting to reveal physical differences between the brains of people with and without chronic pain. This suggests doctors should be looking at people's brains when there is no obvious physical explanation for their pain. "If doctors examine a patient and see nothing, they don't understand why the person is feeling pain," says Marwan Baliki at Northwestern University in Chicago. "But they are looking at the wrong region – they are looking at the back or stomach, for example, when they should be looking at the brain."

In a recent study, Baliki and his colleagues scanned the brains of people with back pain, and re-scanned them several times over the following three years. They found that two brain structures in particular – the hippocampus, which is the brain's memory hub, and the amygdala, which processes emotion – were 10 to 15 per cent smaller in people who went on to develop chronic pain. "The brain was the strongest predictor of whether a person's pain became chronic or not," says Baliki.

In the US, **259 million** opioid prescriptions were dished out in 2012 – more than one for every adult

SOURCE: ASAM.ORG/DOCS/DEFAULT-SOURCE/ADVOCACY/OPIOID-ADDICTION-DISEASE-FACTS-FIGURES.PDF

12 per cent of adults in the UK take prescription painkillers

What's more, those who went on to develop chronic pain lost grey matter unusually quickly in the years that followed. "Patients with persistent chronic pain experience about 8 to 10 per cent greater grey matter loss than those without pain," says Baliki. Each year lived in chronic pain causes as much brain shrinkage as 10 to 20 years of healthy ageing, he adds.

His team are studying mice to investigate why some people might have smaller hippocampi and amygdalae to begin with, and how this might affect their chance of developing chronic pain.

As for the cause of grey matter loss, there's evidence that the immune system might be involved. Researchers started entertaining the idea in the 1970s, after they noted that people in chronic pain display "sickness behaviour", becoming lethargic, anxious and sometimes depressed. This is a well known side effect of the immune system's inflammatory response, which is thought to have evolved to encourage us to rest when ill or injured.

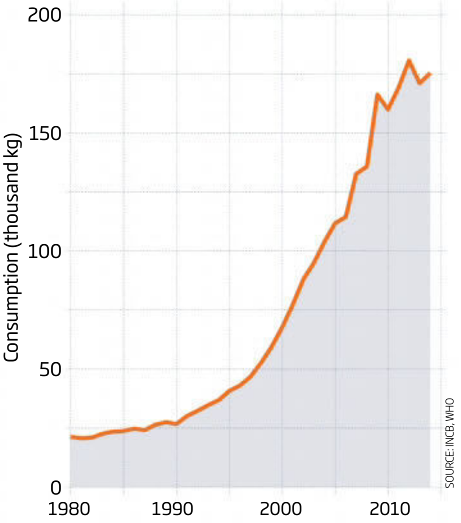
In the brain, the inflammatory response is linked to glia – brain cells that outnumber ›

MARTIN LEON BARRETO

Four out of every **five** new heroin users in the US started out on prescription opioids

On the up

Opioid drug use has rocketed over the past few decades, but there is no evidence they work long term



SOURCE: INCB, WHO

neurons and fulfil a structural and maintenance role in the brain. Some forms of glia stimulate inflammation, while others filter harmful substances, repair injuries or clear debris. Using a chemical that binds to active cells, Loggia's team were able to track their activity in people who had had chronic back pain for two years or more and people without chronic pain.

Pain in the brain

Sure enough, they found striking differences between the groups, with those experiencing pain having significantly higher glial activity than the pain-free participants. The difference was most pronounced in sensory areas corresponding to the site of their back pain and in the thalamus, a region that acts as a gateway from the senses, including the sensation of pain. "You could just look at an individual's scan and tell by eye whether they had chronic pain or not," says Loggia.

They have since used the approach to look at the brains of people with fibromyalgia, a mysterious syndrome that causes pain all over the body. Volunteers with fibromyalgia also had more active glial cells in their brains, although this time in the cerebellar cortex and the medulla – regions that are linked to movement and automatic functions like breathing and digestion. Why they might also have a hand in pain is not yet clear.

Nevertheless, the findings suggest that different types of chronic pain could be described as different brain immune disorders, each with a particular pattern of glial cell activity, says Loggia, who presented the work at the World Congress on Pain in Yokohama, Japan, in September.

Whatever triggers the immune system in the first place, its involvement makes sense because we know it can affect pain directly. Research in animals has shown that the chemicals produced by glial cells can act to sensitise the nerve pathways that deliver pain signals, lowering their trigger threshold. "They essentially turn up the pain volume," says Peter Grace at the University of Texas MD Anderson Cancer Center.

They might also be responsible for the brain shrinkage seen in chronic pain. In healthy brains, glia help shape the connections between brain cells to optimise the communication between them. Over-active glial cells might prune too many connections.

If confirmed, these findings could have huge implications for people living in chronic pain, many of whom feel they are not believed by their doctors, employers or even friends and family, and are accused of being lazy or making things up. "A lot of people see fibromyalgia patients as a bunch of malingerers – that there's nothing wrong with them," says Loggia. "If we can show that there is inflammation in the brain, we can provide more evidence that the disorder is real."

The research could also point to new treatments for chronic pain. Drugs that dampen down the activity of glial cells might be one option, and several candidates are in clinical trials. The hope is that such treatments could be given to people before their brains become sensitised and their pain becomes chronic. "If we could shut down glial cells, we could shut down the pain sensation," says Grace.

Even if these kinds of treatments work, they are unlikely to be enough on their own. Chronic pain is a complex beast. As the disorder develops, it implicates more brain regions, such as those involved in emotion and memory, changing their activity, too.

Recent research has shown that emotion-linked pain has a separate pattern of activity that is distinct from pain processed from a site of injury. While both networks are active in response to an injury, the emotion-linked pain signature is what neuroscientists commonly see in the brains of people with chronic pain whose physical symptoms of injury have healed. This suggests that the signals from psychological pain networks may take over when the problem becomes chronic.

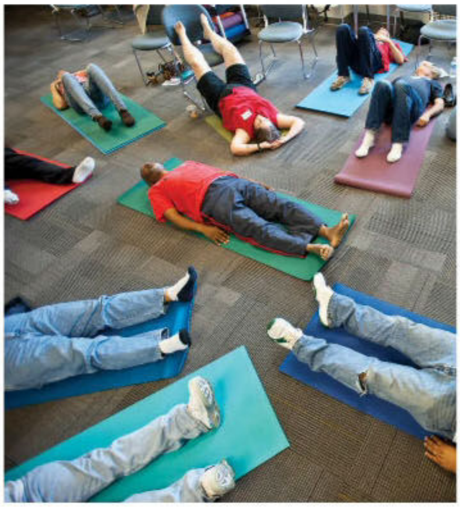
This raises the possibility that psychological interventions might be effective. A 2010 review of 30 studies concluded that, for people with chronic lower back pain, cognitive behavioural therapy and other coping techniques are more effective than standard treatments.

People can even be trained to more directly influence their own brain activity and, potentially, turn down the pain signal. In neurofeedback, electrodes placed on participants' scalps are linked to a real-time display of their brain's electrical activity. With training, people can learn to alter their brain activity to dial down their pain. Preliminary studies suggest that neurofeedback might be useful for people with fibromyalgia, as well as those with chronic pain resulting from spinal cord injuries and cancer.

Mindfulness meditation is a lower-tech way to achieve something similar. The goal is to achieve a state of "detached observation", which can help people cope with pain. Studies so far suggest that it improves various types of chronic pain, including fibromyalgia and lower back pain. What's more, a study of 17 people who practised mindfulness-based stress reduction found that, over time, meditators experienced increases in grey matter in regions of their brains involved in learning, memory and emotion – all of which influence pain perception. It's also cheap, and can be done anywhere with a little training.

Exercise is helpful, too, although if the pain starts with an injury, it can prove both physically and mentally challenging. If a person learns that a movement is painful,

Learning to cope with pain through exercise may be more effective than drugs



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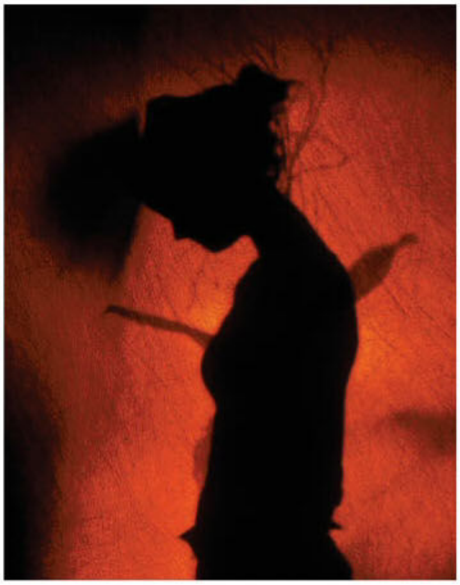


CAROLINE BARBERA/PICTURETANK

Many of those with chronic pain feel that people don't believe them

or a limb is delicate, the information can become crystallised in the brain, almost like a phobia. In these cases, it can be worth re-learning to move the body. Evidence suggests that exercise can improve the symptoms of lower back pain and chronic fatigue syndrome, which also causes pain.

Advocating these non-pharmacological approaches might sound controversial – surely no one wants to be told they just have to think positive or move more. But people with chronic pain are desperate, and most will try anything. "If you'd have told me to stand on my head and bark like a dog, I would have done it if it might help my pain," says Payne.

What is most important is that we all recognise chronic pain for what it is – a neurological disorder in dire need of effective treatment. "These aren't weak people – they have a physical disease in their brain and spinal cord," says Grace.

For her part, Payne has taken matters into her own hands, seeking out talking therapies and alternative remedies to help manage her brain's response to her pain. And while we wait for better treatments to become available to all, she advises others to read as much as they can about their condition. "One of the first things I did was educate myself about pain," she says. "That education has brought me a certain peace of mind that I'm not going mad." ■

Jessica Hamzelou is a reporter at *New Scientist*

ITCH

What is itch for, and what does it have to do with pain? **Stephani Sutherland** investigates

When pain feels good

AS WE improve our understanding of chronic pain, there is a related problem that has researchers scratching their heads.

The sensation of itch, which shares many nervous pathways with pain, has long been a mystery. One reason is that it can be conjured up entirely by the brain. Just thinking about something tickly, or even watching someone else scratch, can set us off. Efforts to find out why this is, and why only scratching makes it stop, have led researchers to study how itch is processed in the skin, spinal cord and brain. In recent years they have begun piecing together a more complete story of what itch is for – and what to do when an itch can no longer be scratched.

165,000 people in the US died from prescription opioid overdoses between 1999 and 2014

SOURCE: CDC.GOV/DRUGOVERDOSE/DATA/OVERDOSE.HTML

Itch, like chronic pain, is a surprisingly common problem. It comes as a side-effect of opioid painkillers, the use of which has rocketed in recent years (see graph, p 36). It also comes with skin conditions such as eczema as well as nerve damage, kidney disease and allergies. An estimated one in five of us will experience chronic itch at some point, and current remedies are providing little relief.

The most common treatments are antihistamines, which block the part of the immune reaction that causes itching when we are bitten by a bug, for example. Not all itches are immune-related, however, and antihistamines have proven to be ineffective for most forms of chronic itch. Neuropathic itch, which stems from damage to sensory nerves in the skin, has no effective treatment.

In recent years, researchers have discovered new kinds of receptor in the skin and spinal cord that play a role in the sensation of itch. They are working to figure out what naturally activates these receptors in the hope of designing drugs that can deactivate them.

For now, though, the single most effective way to get rid of an itch is what we do instinctively: to scratch. But why do we rake our nails across our skin, when it causes pain and, potentially, tissue damage?

The answer lies in the way that the spinal cord is wired, says Sarah Ross, a neurobiologist at the University of Pittsburgh. Neurons that transmit long-distance messages between the body and the brain are bridged by smaller ›

"Contagious itch may have evolved as a social signal to warn that parasites are nearby"

In 2014, almost **2 million** people in the US abused or were dependent on prescription opioids

SOURCE: SUBSTANCE ABUSE AND MENTAL HEALTH SERVICES ADMINISTRATION, NATIONAL SURVEY ON DRUG USE AND HEALTH, 2014

cells called interneurons. These can either be excitatory, spurring messages towards the brain, or inhibitory, stopping the messages dead. Scratching works because the body processes this sensation as more urgent than itch, so inhibitory interneurons halt the itch message and fast-track the pain signal instead.

There are several different types of interneurons in the spinal cord, though, and not all of them require pain to stifle itch. For example, Ross has found that in mice, the neurons that detect the sensation of coolness from a cold compress or menthol make direct connections with a type of interneuron that prioritises the sensation of coldness over itch.

Qiufu Ma, a researcher at Harvard Medical School, identified another group of interneurons in the spinal cord that respond to a tickling sensation on the skin. Sensory neurons that transmit this kind of itch may be among the most sensitive neurons in the peripheral nervous system, Ma says. When stronger pressure activates other mechanically sensitive neurons, the tickle is stopped in its tracks to allow the stronger sensation to pass. The fact that pressure has the same effect on the interneurons as the pain caused by scratching suggests that rubbing can be as effective as scratching, and there is no need to tear at your skin with your nails.

Further clues on how to tackle itch come from brain imaging studies. Many brain areas activated by pain are also active during itch, but one area that seems distinctively responsive to itch is the precuneus. This brain region is involved in visual processing and memory, says Gil Yosipovitch at the University of Miami, Florida. "We can't pinpoint what the precuneus does in itch, but it's uniquely activated with itch and not pain," he says.

Yosipovitch has also shown that the act of scratching activates pleasure centres of the brain, which explains why scratching an itch feels so good. This pleasure seems to be particularly strong for people with chronic itch conditions. "The more itch you have, the higher the pleasure you get from scratching," he says. The fact that the pleasure of scratching only activates the reward circuits more over time explains why the itch-scratch cycle is so hard to break once the problem becomes chronic.

He has also found that people with chronic itch are more sensitive to contagious itch – that irresistible urge to join in when someone else is scratching. Contagious itch is thought to have evolved as a social signal, much like contagious yawning. The idea is that joining in when seeing someone else scratch would give people a headstart in dislodging any parasites that might be around.

Those brain signals might be strengthened over time in people with chronic itch, suggests Yosipovitch. Whether that happens purely as a result of experience, or whether some people's wiring predisposes them to itch or pain remains something of a chicken-and-egg question.

One important realisation, says Yosipovitch, is that there are many types of itch, each of which activates different nerve cells and brain circuits. "Not all types of itch are equal." And while the advances in our understanding of itch haven't yet translated into new treatments, the same psychological interventions that are working in chronic pain could help people live with itch. "Stress is one of biggest aggravating factors," says Yosipovitch. ■

Stephani Sutherland is a science writer based in Southern California

Scratching damages the skin but also activates pleasure pathways

VLADIMIR SEROV/GETTY

ARTIFICIAL INTELLIGENCE PART TWO

Most of us encounter artificial intelligences every day, but their workings are hidden from us. So what is going on inside the black box?

Illustrations by *Leandro Castelao*

A DIFFERENT WAY OF THINKING

Artificial intelligences may not understand things like we do, but what they can achieve is still staggering, says **Nello Cristianini**

CAN a human-made creature ever surprise its creator, taking initiatives of its own? This question has been asked for centuries, from the golem of Jewish folklore to *Frankenstein* to *I, Robot*. There are various answers, but at least one computing pioneer knew well where she stood. "The Analytical Engine has no pretensions whatever to originate anything," said Ada Lovelace, Charles Babbage's collaborator, in 1843, removing any doubt about what a computing machine can ever hope to do. "It can do whatever we know how to order it to perform," she added. "It can follow analysis; but it has no power of anticipating any analytical relations or truths."

But 173 years later, a computer program developed just over a mile away from her house in London beat a master of the game Go. None of AlphaGo's programmers can come close to defeating such a strong player, let alone the program they created. They don't even understand its strategies. This machine has learned to do things that its programmers can't do and don't understand.

Far from being an exception, AlphaGo is the new normal. Engineers began creating machines that could learn from experience decades ago, and this is now the key to modern artificial intelligence (AI). We use them every day, usually without realising it.

GILLES COULON/TENDANCE FLOUE

Many of us use artificial intelligence every day, often without realising it

For programmers who develop such machines, the whole point is to make them learn things that we don't know or understand well enough to program in directly. This approach – called machine learning – has been extremely fruitful. It is the secret sauce of modern AI and has delivered recent successes (and spectacular failures) in autonomous cars, product recommendations, personal assistants, Go and more.

How can a machine learn? When I was growing up, my bicycle never learned its way home and my typewriter never suggested a word or spotted a spelling mistake. Mechanical behaviour was synonymous with being fixed, predictable and rigid. For a long time, a "learning machine" sounded like a contradiction, yet today we talk happily of machines that are flexible, adaptive, even curious.

In artificial intelligence, a machine is said to learn when it improves its behaviour with experience. To get a feel for how machines can perform such a feat, consider the autocomplete function on your smartphone.

If you activate this function, the software will propose possible completions of the word you are typing. How can it know what you were going to type? At no point did the programmer develop a model of your intentions, or the complex grammatical rules of your language. Rather, the algorithm proposes the word that has the highest probability of being used next. It "knows" this from a statistical analysis of vast quantities of existing text. This analysis was done mostly when the autocomplete tool was being created, but it can be augmented along the way with data from your own usage. The software can literally learn your style.

The same basic algorithm can handle different languages, adapt to different users and incorporate words and phrases it has never seen before, such as your name or street. The quality of its suggestions will depend mostly on the quantity and quality of data on which it is trained. So long as the data set is sufficiently large and close in topic to what you are writing, the suggestions should be helpful. The more you use it, the more it learns the kinds of words and expressions you use. It improves its behaviour on the basis of experience, which is the definition of learning.

Note that a system of this type will probably need to be exposed to hundreds of millions of phrases, which means being trained on several million documents. That would be difficult for a human, but is no challenge at all for modern hardware.

Nello Cristianini is professor of artificial intelligence at the University of Bristol, UK

If you feel that this is cheating, because the algorithm is not really intelligent, then brace yourself. Things get worse.

The next step up in complexity is a product recommendation agent. Consider your favourite online shop. Using your previous purchases, or even just your browsing history, the agent will try to find the items in its catalogue that have the highest probability of being of interest to you. These will be computed from the analysis of a database containing millions of transactions, searches and items. Here, too, the number of parameters that need to be extracted from the training set can be staggering: Amazon has more than 200 million customers and in excess of 3 million books in its catalogue.

Matching users to products on the basis of previous transactions requires statistical analysis on a massive scale. As with autocomplete, no traditional understanding is required – it does not need psychological models of customers or literary criticism of novels. No wonder some question whether these agents should be called "intelligent" at all. But they cannot question the word "learning": these agents do get better with experience.

EMULATING BEHAVIOUR

These are just the simplest examples. Using the same or similar statistical techniques, in multiple parts of a system and at various scales, computers can now learn to recognise faces, transcribe speech and translate text from one language to another (see "Bots in translation", right). According to some online dating companies, they can even find us potential love matches. In other words, they can emulate complex human behaviours that we cannot fully model. But they do it in a way that is very different from what we do.

Things can get more complicated. Online retailers keep track not just of purchases, but also of any user behaviour during a visit to the site. They might track information such as which items you have added to the basket but later removed,

›

The bicycle is a quintessential example of a non-learning machine

TOP RIGHT: ALEX SEGRE/ALAMY STOCK PHOTO, RIGHT: GETTY

BOTS IN TRANSLATION

One of the most impressive feats of modern artificial intelligence is translating text from one language to another. Google's tool, for example, can translate with reasonable competence between 135 written languages, from Afrikaans to Zulu.

Most machine-translation products don't have linguistic rules programmed into them. Instead, they apply statistical techniques to large data sets.

The text to be translated is first broken into words or phrases, each of which is then compared with a table of available translations and their probabilities of being accurate. There will be multiple ways to divide up the source sentence, and multiple ways to translate each phrase. The problem is how to select from among these possible translations and assemble them into a sentence in the target language that is both grammatical and an accurate translation.

This is computationally hard, but modern computers can do it. The probabilities required for such calculations are stored in two tables containing phrases and probabilities – the first one providing a statistical model of the target language, and the second a list of all phrases in the source language and their possible translations. That is where all the knowledge of the system lies. Change some entry, and the system will behave differently. Improve the estimation of probabilities, and it will boost its performance. No understanding of the text is needed, just statistical patterns.

The source of the information in those tables is, of course, vast data sets such as the proceedings of the European Parliament, which are translated into 23 languages. Challenging? Yes. Still prone to error? Yes. Teaching us something about how humans extract meaning from sentences? Hardly.

> *"We can expect to reap the benefits of data-driven artificial intelligence for many years to come"*

which you have rated and what you have added to your wish list. Yet more data can be extracted from a single purchase: time of day, address, method of payment, even the time it took to complete the transaction. And this, of course, is done for millions of users.

As customer behaviour tends to be rather uniform, this mass of information can be used to constantly refine the agent's performance. Some learning algorithms are designed to adapt on the fly; others are retrained offline every now and then. But they all use the multitude of signals extracted from your actions to adapt their behaviour. In this way, they constantly learn and track our preferences. It is no wonder that we sometimes end up buying a different item from the one we thought we wanted.

Intelligent agents can even propose items just to see how you respond. Extracting information in this way can be as valuable as completing a sale. Online retailers act in many ways as autonomous learning agents, constantly walking a fine line between the exploration and exploitation of their customers. Learning something they did not know about you can be as important as selling something. To put it simply, they are curious. A similar strategy could be used by spam filters and any other software that needs to learn your preferences and predict your actions. One day soon, the appliances in your house will be interested in predicting your next action too.

Machine learning is not just about analysing past behaviour. Sometimes AIs need to deal with novel situations. How do you help a new customer? To whom do you recommend a brand new book? The trick in this case is to get machines to generalise, using information from similar customers or products. Even a customer who has never used the service before leaves a small data trail – an email address and location, for example – to get started on. The ability to detect and exploit similarities is sometimes called pattern recognition, and its importance is not limited to "cold start" situations. In fact, generalisation – detecting patterns and similarities – is a fundamental part of intelligent behaviour.

But what does it mean that two items are similar? We could describe a book by the number of pages, the language it is written in, the topic, the price, the date of publication, the author, even some index of its readability. For a customer, useful descriptors might include age, gender or location. In machine learning, these descriptors are sometimes called features or signals. We can use them to locate similar items for which we have sufficient data. The machine can thus generalise from one situation to a similar one, and make better use of its experience.

Choosing the right features is one of the critical problems in machine learning: the font used in a book might not be as useful as its price, for example. This problem becomes even more critical when we handle complex items such as images. If you compare two passport photos of yourself taken one minute apart, they will not be identical at the level of raw pixels. This is sufficient for the computer to treat them as two completely different images. We would like the computer to represent those images in a more robust way than just using pixels, so it does not get confused by small irrelevant changes in the image. Which features of an image should be used in order to recognise the same face in different photos?

This has been a surprisingly stubborn problem, made worse by the variation in lighting, position and background that can occur in natural scenes.

Programming this capability directly into a computer has proven difficult, so engineers have once more resorted to machine learning. One such method, called deep learning, is currently delivering the best results in some domains (see "Layers of learning", right). As with the earlier examples, it involves using big data to adjust millions of parameters.

UNDER THE BONNET

Consider now that these nuts and bolts of machine learning can be applied to many parts of the same system at the same time: a search engine might use them to learn how to complete your queries, best rank the answers for you, translate a document among the search results and select which ads to display. And this is just on the surface.

Unknown to users, the system will probably also be running tests to compare the performance of different methods by using them on different random subsets of

This is the second part of our Instant Expert on artificial intelligence. The first part was published in the 29 October issue

ISSOUF SANOGO/AFP/GETTY IMAGES

Unknown to users, AI systems are constantly running tests on us

users. This is known as A/B testing. Every time you use an online service, you are giving it a lot of information about the quality of the methods being tested behind the scenes. All this is on top of the revenue you generate for them by clicking on ads or buying products.

While each of these mechanisms is simple enough, their simultaneous and constant application on a vast scale results in a highly adaptive behaviour that looks intelligent to us. AlphaGo learned its winning strategies by studying millions of past matches and then playing against various versions of itself for millions of further matches. An impressive feat. Nonetheless, every time we understand one of the mechanisms behind AI, we cannot help feeling a little cheated. AI systems generate adaptive and purposeful behaviour without needing the kind of self-awareness that we like to consider the mark of "real" intelligence. Would Lovelace dismiss their suggestions as unoriginal? Possibly, but while the philosophers debate, the field keeps moving forward.

What, then, is the road ahead? Science often progresses via paradigm shifts, and AI is probably no exception. We are now in the middle of a very fruitful paradigm – data-driven AI – and we can expect to reap its benefits for many years. We should expect increasingly autonomous cars, increasingly fluent machine translators, and ever-cleverer cameras, phones and homes.

Should we also think that this is the last word in this most ambitious of fields? Is this really the way in which we are going to be building the intelligent machines that will follow us in our journeys to the planets and beyond? I think not. The history of science suggests that we haven't seen the last revolution in AI. But where the next paradigm will emerge from, and what it will be capable of, is impossible to predict. ■

LAYERS OF LEARNING

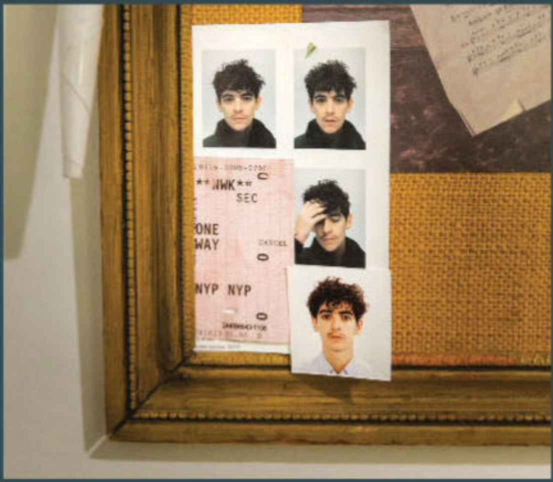
One of the buzz phrases in artificial intelligence research is "deep learning". It sounds exotic but is actually another form of the data-driven approach that has delivered so many successes in AI in recent years. Deep learning relies on a technology called neural networks, and has proven to be a valuable tool for solving hard perceptual problems such as recognising images.

Consider two photographs of the same face. They can vary enormously. A big unresolved problem in AI is how to identify the features that remain invariant despite differences in the raw sensory data, and how to use them to recognise the photos as being of the same face.

Originally based on a loose biological analogy with the human cortex, neural networks have been developed into complex mathematical objects. The raw sensory information – for example, the pixels of an image – is processed as it flows through a network of simple "neurons", each specialised in recognising some aspect of the data. Lower-level neurons detect simple features of the image – straight lines, say – and feed that information to higher-level neurons, so that increasingly complex properties of images can be detected.

Crucially, these networks can adapt and improve with training, so that the most informative and stable features of an image can be discovered and used by the network without being directly programmed in by a human.

In their previous incarnations, neural networks were not particularly useful, but with modern hardware and giant data sets they have found a new life, delivering the best performance in certain perceptual tasks – most notably in vision and speech. Deep learning is typically used as a component in larger machine-learning systems (see main article).


ROB HOWARD/GALLERYSTOCK

Send in the genes

Gene therapy once promised to revolutionise medicine, but things went terribly wrong. Twenty years on, that promise has been renewed by scientists like **Alessandra Biffi**, who are wielding genes to fight previously untreatable conditions

PROFILE
Alessandra Biffi is associate professor of paediatrics at Harvard Medical School and director of the gene therapy programme at Dana-Farber/Boston Children's Cancer and Blood Disorders Center

What is gene therapy?
It is a way to fix a gene defect in a person's cells. One way is with a retrovirus. When these viruses infect cells, they are able to transcribe genetic information into the cell's DNA. So we genetically engineer the virus to incorporate the gene a person needs. We can then inject the virus directly into their blood or tissue, or collect cells from them, make changes in a lab, and then reinject the corrected cells.

There were some major setbacks 20 years ago. What happened?
There were a few different issues. One was related to immune responses to the virus, which had harmful effects that were not foreseen. Another significant issue was that in trials treating immune deficiency diseases, some children were successfully treated but then developed leukaemia. That was because of the integration of DNA from the virus into the genome of their haematopoietic stem cells – the cells that give rise to all our blood cells.

So is it safer now?
There have been many changes in the viruses used for gene transfer. Those we use today can make changes to cells that are not actively dividing and interact differently with the host cell's DNA. They are more neutral in how and where they make changes – not accidentally activating neighbouring genes, for instance. All of these things mean that they have a much lower chance of impacting cell behaviour and growth beyond the expression of the specific gene that we have added.

Will gene therapy now become more widespread?
Two gene therapy treatments have recently been approved by the European Medicines Agency. There are hundreds of clinical trials going on now. For instance, the results of a trial treating an immune deficiency disease called SCID were recently published. Years after the treatment, there has been no indication of any cancer in the patients.

Everyone's now talking about CRISPR gene editing. Does it change things?
I think it has huge potential, both in terms of innovation and therapeutic opportunities for patients. Gene editing presents the possibility of correcting the gene mutation locally, instead of inserting new information. It could potentially provide more safety for patients. It's really opening a new era.

But will CRISPR make the type of genetic engineering that you do, using viruses, unnecessary?
It's very early to say. I think we have plenty of space for parallel investigations that would allow us to identify the best options for patients. We will probably end up with multiple modalities, just as we have many different medicines in general.

Were early expectations of gene therapy unrealistic?
There were a lot of expectations 20 years ago, then there was a big drop related to side effects. Now everybody is again climbing to the top of the hill. But whether there is too much or too little enthusiasm doesn't change the fact that development of gene therapy as a treatment is a process.

When you introduce something into your body with curative intent, it's a drug – so gene therapies, too, need to be considered as drugs. That means they require clinical development and monitoring, because every drug works best in certain circumstances and has side effects. What is also really important to keep in mind is that we are talking about drugs in an early phase of development.

You recently led a trial using gene therapy to treat a deadly childhood disease. Can you tell me about it?
It is a very severe neurodegenerative disease called metachromatic leukodystrophy (MLD), and it mostly affects young children. It's devastating. These children have a normal early infancy and develop normally. Then at some point, often around 18 months old, they

KEN RICHARDSON FOR NEW SCIENTIST

start to experience a progressive loss of abilities – movement, cognitive skills, language, the ability to interact. They become unable to swallow, to talk. You can imagine how intense that can be for their families. Children affected in infancy seldom survive into adolescence.

How did you treat it?
The trial, which I began and is still ongoing at the San Raffaele Telethon Institute for Gene Therapy (SR-TIGET), involves extracting haematopoietic stem cells from the patients' bone marrow and then using retroviruses to insert the missing gene into them.

While the stem cells are being prepared, the patients undergo chemotherapy – basically to wipe out the remaining haematopoietic cells and clear the way for the corrected cells.

This is a disease affecting neurons. Why do you insert the gene into blood cells?
We used blood cells partly due to their accessibility, but also because we have had more practice working with them. There has been some work with neural stem cells, but it is very early days.

People with MLD cannot produce an enzyme critical for protecting the myelin around their neurons. When the corrected cells reach the brain, they give rise to progeny that deliver the enzyme. The blood cells' ability to do this has made them a particularly potent form of treatment. We are now looking at using this strategy to make changes in the brain in other neurodegenerative disorders.

What are the results of the MLD trial so far?
Of the nine children in whom the follow-up is at least three years – long enough to provide an indication – some have shown no symptoms, despite reaching an age well beyond when we would have expected to see them. Others have had a milder course of the disease.

When you extract cells from the patient, genetic alteration can be done remotely. Will that make gene therapy more accessible?
It is already happening. An initiative has just been launched by David Williams at Dana-Farber/Boston Children's to centralise manufacturing of patient haematopoietic stem cells. It will provide training to enable satellite centres to administer gene therapy, so people can remain in their local hospital.

> **"Some of the children now show no symptoms of this fatal genetic disease"**

This initiative could also be applied to clinical trials. There are already some in which this is being tested. You really need standardisation and coordination of the work for gene therapy to become more widespread.

For many, these clinical trials are their only hope. It must be hard to turn people away.
It's very challenging. With MLD, I knew the disease so well, and its devastation, but at the same time was aware of the many unanswered questions about the new therapy. They could only be answered with clinical trials. It has been extremely difficult to say no, but you have to avoid exposing children to risks if they would not stand to benefit. You also have to complete your trials and demonstrate the treatment works – or else the path to developing a medicine for more people is that much longer.

Whenever you see that your therapy is really affecting the life of a child, you feel that your hard work really had a purpose. That is why we are doing all this. ■

Interview by **Tiffany O'Callaghan**

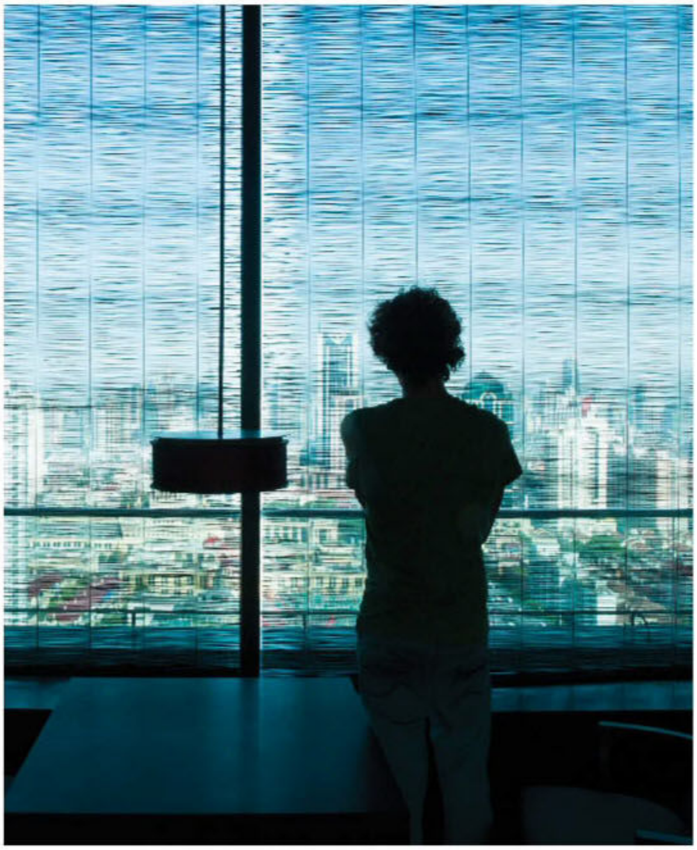
Loving it…

Tales of first contact, living an alien life in Earth's cities and a gloriously reinvigorated TV classic: our picks show why 2016 is a year to remember

ROWAN HOOPER, MANAGING EDITOR

Arrival, directed by Denis Villeneuve, UK cinemas

Aliens have landed on Earth, but instead of sending in an action hero to fight them, *Arrival* dispatches linguist Amy Adams to attempt to communicate with them. The result is a different, more moving and more intriguing film than you might expect from the premise. "Language is the first weapon drawn in a conflict," we are told. The big question the military want her to ask the aliens: what is their purpose on Earth? The twist in *Arrival* will leave you pondering for days, but this movie is far more about human understanding, memory, love and fortitude – and linguistics – than it is about alien invasion.



JASPER JAMES/MILLENNIUM IMAGES, UK

STEPHANIE PAIN, CONSULTANT

Planet Earth II, BBC Natural History Unit, BBC1

There have been plenty of reasons to shout at the TV this year, but I've only screamed out loud once. And yes, it was that jaw-dropping footage of snakes versus newly hatched iguanas that set Twitter alight and the tabloid papers spluttering. Every time David Attenborough presents us with a new natural history blockbuster, you think there can't be any stories he hasn't already told and the filming can't get any better – but there are, and it does. The marine iguanas' race to the sea was just the start. When Komodo dragons clash, we see every shining drop of spittle and every glinting scale; when Nubian ibexes dance their way down sheer cliffs, we see their hooves in action. And thanks to remote camera technology, the snow leopard, elusive for so long, now comes so close you could reach out and touch it. Almost unbelievably magnificent.

VICTORIA TURK, TECHNOLOGY EDITOR

Stranger Things, directed by the Duffer Brothers, Netflix original series

A mysterious disappearance, a shady research facility, a girl with telekinetic powers and a monster in the woods. *Stranger Things* has all the twists you might hope for in a supernatural thriller, brought to life in a meticulously recreated 1980s setting. Complete with a synth-heavy soundtrack and Winona Ryder in a starring role, the throwback aesthetic makes for a delightful homage to classic science fiction films. But make no mistake: this show isn't a breezy nostalgia trip – you'll be on the edge of your seat.

FRANK SWAIN, COMMUNITIES EDITOR

ARQ, directed by Tony Elliott, Netflix original film

In recent years, we've seen a crop of films exploring the multiverse, from the literal *Another Earth* to the hallucinatory *Coherence*. Taking its place alongside these is *ARQ*, a cat-and-mouse thriller that adopts the same stuck-in-a-time-loop premise as the Tom Cruise blockbuster *Edge of Tomorrow*, but throws a chaotic twist into the mix: what if both the cat and the mouse knew they'd been through this all before?

JULIAN RICHARDS, HEAD OF PRODUCTION

Space Gallery, World Museum, Liverpool, UK

Up to the fifth floor, past the cafe. Many of the displays hadn't changed since I last visited as a child in the 1970s. So what? The huge gleaming cylinder of the Black Knight rocket – from the days when the UK had its own space programme – still hung over my head, frozen in mid-flight. The planetarium is still introducing handfuls of visitors to the constellations. The lighting is still as stark as a chapel. And look, you wouldn't believe it, but over there, under a plastic covering, those stones are bits of the moon.

LIZ ELSE, ASSOCIATE EDITOR/ CULTURE EDITOR

Lo and Behold, Reveries of the connected world, directed by Werner Herzog, UK cinemas

There is nothing like being up a creek without a paddle. And veteran film-maker Werner Herzog knows all about that – think of his *Aguirre*, *The wrath of God* or *Fitzcarraldo*, where everyone goes mad negotiating increasingly hostile environments as they pursue inherently insane quests. So when Herzog tackles the origins and future of the internet, no matter how faux naively, we really do know where he stands. You only have to watch the mournful contribution of space pioneer Elon Musk, or the sharp words of prescient academic Jonathan Zittrain to get the message. I really liked it, despite the sound of distant drums upstream.

ROWAN HOOPER

Death's End (Remembrance of Earth's Past, volume 3) by Cixin Liu, translated by Ken Liu, Tor Books, £21.97

As my second choice, I have gone for the final part of Cixin Liu's trilogy, which was published in English this year. "Epic" is far too small a word for it: I haven't read many books as ambitious or far-reaching in their scope as this. Based around the first contact with an alien species, presciently located in the Proxima Centauri system only 4 light years away from Earth, Liu has created an extraordinarily imaginative work, full of mind-bending science and science fiction.

SIMON INGS, CULTURE EDITOR

The Language of Cities by Deyan Sudjic, Allen Lane, £25

This year, I've been working a lot from home – on the 33rd floor of a desert-facing block built atop a deserted shopping mall. It's in Dubai, home to three million residents, of whom only 15 per cent are citizens. Colleagues who look askance at this compact, stripped-down corporate city-state live mostly in London, a much stranger, more amorphous place, whose appetites, if we are to believe Deyan Sudjic, director of London's Design Museum, shape the geographies of cities as far apart as Bournemouth and Baghdad. Sudjic's *The Language of Cities* tries to make sense of all the world's cities in 219 pocket-sized pages. It proved to be one of the oddest good books I have ever read – which didn't surprise me in the least.

GRAHAM LAWTON, EXECUTIVE EDITOR

New Scientist: The origin of (almost) everything, John Murray, £25

It may not be the done thing to recommend a book I wrote, but this really is my pick of the year. Every society has stories about where the cosmos and its inhabitants came from. The oldest we know of is the 2700-year-old Enuma Elish from Babylon, but they surely go further back. Their creators did not have much to go on: more often than not they fell back on the supernatural. We can do better because science has supplied us with origin stories galore. In this book I've brought together 53 of the most important, unexpected and quirky, from the big bang to belly button fluff via the formation of Earth, the origin of life, the dawn of civilisation and the age of invention. With infographics by Jennifer Daniel and an intro by Stephen Hawking.

ELIZABETH WHITE/BBC NHU

PARAMOUNT/COURTESY EVERETT COL/REX/SHUTTERSTOCK

NETFLIX

MAGNOLIA PICTURES/REX/SHUTTERSTOCK

Far left: making sense of the city Top: iguanas storm Twitter. Middle: talking to aliens. Below left/right: SF homage; inside the internet

JEFF HECHT, CONSULTANT

The Lowell Folk Festival, Lowell, Massachusetts, US

The annual Lowell Folk Festival is a weekend that reminds me just how deeply embedded music is in human nature, and how well it can cross boundaries. The wonderfully varied performers included a family of Cajun musicians from Louisiana, an escaped Iraqi political prisoner now living in Arizona, who played the oud (a fretless Arabian lute), and King Sunny Adé from Nigeria playing juju, a hybrid of traditional Yoruba praise music and drums with guitar and keyboard. It made me wonder afresh if our ancestors made music way before they had words.

ADRIAN BARNETT, RESEARCHER/WRITER

Political Animals: How our stone-age brain gets in the way of smart politics by Rick Shenkman, Basic Books, £17.99

Any book that reminds me of *The Naked Ape* gets my vote. And Rick Shenkman's book shows how instinctive responses override rationality on many occasions, so that what we do at society level may make little sense. I greatly enjoyed its insights but didn't expect it to become quite so blisteringly relevant. ■

Gifts that keep on giving

This great line-up of books will feed the mind throughout the year

PLAINPICTURE/CULTURA/JOHO

1 **Welcome to the Universe: An astrophysical tour** *by Neil deGrasse Tyson, Michael A. Strauss and J. Richard Gott, Princeton University Press, £29.95*
How big is the universe? Is it full of intelligent life? And if so, will we find it? How do stars live and die? What happened to poor old Pluto? And what part did Neil deGrasse Tyson himself play in relegating it to the status of an ice ball in the outer solar system? These are just some of the riveting questions fielded by three top astrophysicists in engaging style, with great illustrations and just a handful of equations. They may just have produced the best book about the universe in the universe.

2 **The Indisputable Existence of Santa Claus: The mathematics of Christmas** *by Hannah Fry and Thomas Evans, Doubleday, £9.99*
Just in case the charm and beauty of mathematical thinking has passed by some of your friends and family, they will be grateful for this slim volume in their stocking. The puzzles and games of Hannah Fry and Thomas Evans involving present-wrapping and Queen's Speech bingo are but an entry drug for heady passages about the nature of truth and game theory.

3 **What's really happening to our planet? The facts simply explained** *by Tony Juniper, Foreword by HRH Prince Charles, DK, £12.99*
It's not looking good, what with unsustainable population growth, degraded natural environments and climate change. We've made inroads on poverty, safer drinking water and literacy, but it's not enough. Welcome, then, an infographics book on the state we're in. As a long-time green campaigner, Tony Juniper was the obvious man to write it – and he has the wisdom to leave us with hope, as we contemplate the rise of small-scale hydropower and onshore wind energy, as well as sustainable, circular economies.

4 **Princeton Field Guide to Dinosaurs (second edition)** *by Gregory S. Paul, Princeton University Press, £24.95*
Gregory S. Paul is back with 100 new species and 200 new or updated illustrations to his vision of the Mesozoic era. Paul will always be the man who helped define the CGI on *Jurassic Park*, changing the look and feel of dinosaurs for a generation. This engaging volume is informed by the latest research, much of it from China. In a fully revised introduction, Paul explores his subject from head to tail, while the passage "If Dinosaurs Had Survived" is sure to leave readers misty-eyed.

5 **Big History: Our incredible journey, from big bang to now** *by David Christian, DK, £25*
In the teeth of the internet's always-on, always-compelling son et lumière, publisher DK still produces illustrated books on… everything. This time, David Christian, co-founder of online teaching course the Big History Project, writes about all the observable universe and all observable time. Savvy readers will enjoy how the volume avoids the obvious pitfalls of collapsing astronomy, anthropology, physics and archaeology into one discipline. The rest of us will drop our jaws in wonder at the endeavour.

6 **Universal: A guide to the cosmos** *by Brian Cox and Jeff Forshaw, Allen Lane, £25*
Some readers eat popular physics for breakfast. Others yearn for a single simple volume to bring them up to speed, thereby freeing them for the fun stuff (life sciences, tech stories, cat videos). Brian Cox and Jeff Forshaw will satisfy both audiences with their broad-brush account of the physical world that still finds room for uncertainty, controversy – even a little light maths. Rarely has a difficult subject been rendered so accessible.

7 **Where the Animals Go: Tracking wildlife with technology in 50 maps and graphics** *by James Cheshire and Oliver Uberti, Particular Books, £25*
This is a special kind of detective story. After millennia of using footprints, faeces, feathers, broken foliage and nests to track animals, the process is now so teched up you need to read this book to find out the how, what and why. Geographer James Cheshire and designer Oliver Uberti worked with researchers and wildlife experts to collect billions of data points, taken from digital tags on humpback whales, magnetic fields tracking badgers, QR codes mapping an individual ant, and more. The last page shows genetic barcodes of the animals, and a human. How similar we look – at least on paper.

8 **US Spy Satellite Owners' Workshop Manual** *by David Baker, Haynes Publishing, £25*
Ever wondered how the US learned to spy on the world from space? Here's the story of the secret tech revolution spawned by the cold war. Developing reconnaissance and surveillance-camera technology to track Russia's military strength was a deeply covert mission in itself. Mull in secret. ■

COMPETITION
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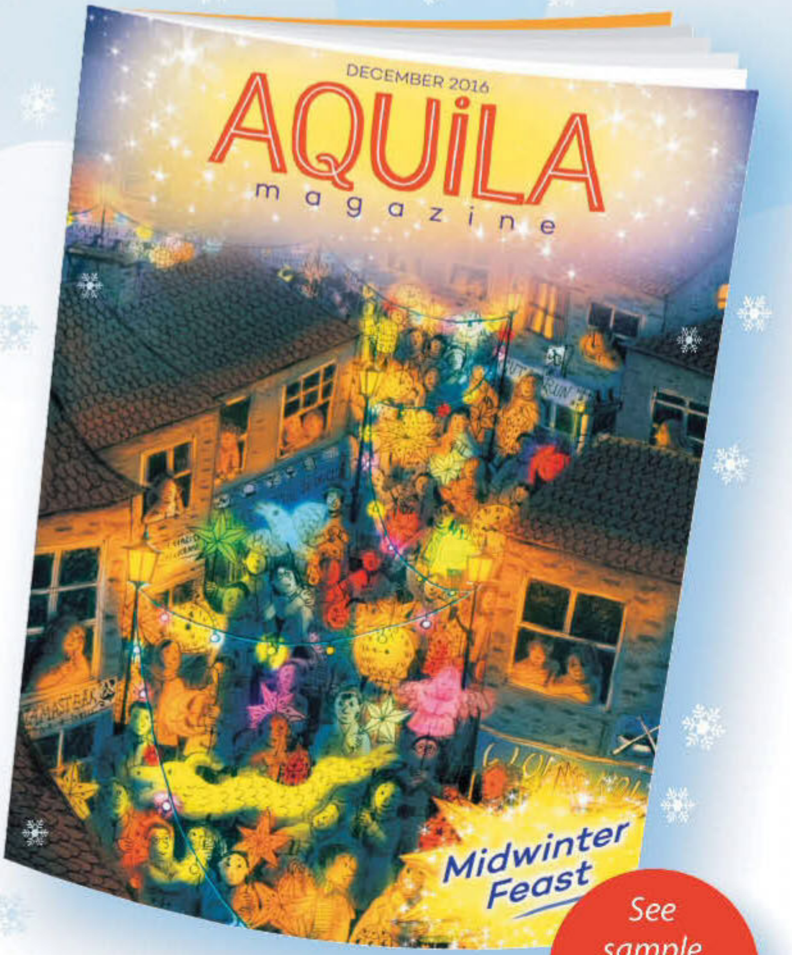

See sample magazine online

AQUILA's Christmas issue

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We can post the December issue with your gift message. The festive package is stamped *'Open on 25th December'*, and is mailed from early December onwards. See more subscription options online at **www.AQUILA.co.uk**

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EDITOR'S PICK

Nostalgia isn't as good as it once was

CRYING ON THE OUTSIDE, LAUGHING ON THE INSIDE – I CAN NEVER REMEMBER...

From Steve Last
Dunfermline, Fife, UK

I was interested to read that recent research reveals a beneficial effect when a person nostalgically recalls good times (24 September, p 36). This is entirely plausible when the person remembering is in a positive (or at least neutral) frame of mind. But intuition – and my experience as a psychiatrist – tells me that recalling better times when a person is depressed will commonly exacerbate their problems rather than improve them.

For example, during a divorce, I'm not sure that it is helpful for a person to focus on all the good times in the marriage. They are likely to experience an even greater sense of loss.

It has been said that, in times of crisis or depression, recalling better times can be "sorrow's crown of sorrow", as the poet Alfred Tennyson put it. In such situations I find it more helpful to focus on possible positive futures rather than the (better) past.

How to square this with the research cited in the article? Perhaps being nostalgic has a positive influence on mood – but only if you aren't depressed.

Putting a price on your life and health

From Chloe Anthias, Medical Director, Anthony Nolan trust
London, UK

Difficult decisions are necessary in a health service with limited resources (22 October, p 5). But patients have a right to robust and transparent decision-making about which treatments are funded. NHS England is reviewing funding for second stem cell transplants for people with blood cancer and blood disorders – which lead to at least five extra years of life in a third of cases.

While a transplant carries an upfront cost, the alternative treatments are also costly and unlikely to save the patient.

The price of a treatment must be considered, but it is equally important to assess the cost of not providing it.

From David Bennett
Beaconsfield, Buckinghamshire, UK

One of your 22 October Leader articles refers to the valuation of life and the need to secure value for money from the public healthcare budget. The other highlights amazing advances in treating infertility, which many couples will desire. Prosthetic joints are no less remarkable a breakthrough, and yet I know of people refused hips and other treatments for reasons of limited public health finances.

As the gap between health technology capability and patient demand grows we need real public involvement in how healthcare provision is prioritised.

From Philip Thomas and Geoff Vaughan
Bristol and Warrington, UK

As researchers in the field of estimating what is legitimate

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“I’ll be damned if I give out my blood to some old ass who don’t even like me”

Tara Parker responds to news that teenage human blood reinvigorates old mice (19 November, p 10).

to spend on safety measures, we understand the need to value human life in financial terms. But we cannot fully accept your statement that the world should embrace the formulae of the UK’s National Institute for Health and Care Excellence (NICE). These are based on the Quality-Adjusted Life Year: but the value of this is linked to the Value of a Prevented Fatality used by the UK’s Department for Transport.

We have shown that this value is devoid of any evidential basis (*Process Safety and Environmental Protection*, doi.org/bs3h). It was based on a 1997 survey of the stated preferences of 167 people. The authors have acknowledged that the research had limitations.

NICE’s basic approach, valuing the increase in life expectancy brought about by a medical treatment, is nevertheless good.

From Trevor Campbell
Berrima, New South Wales, Australia

I enjoyed Shannon Fischer’s article about the price of a life (22 October, p 28). But I’m not sure in what form you buy carbon and sodium. I get carbon for A$100 a tonne in the form of coal, and sodium for A$500 a tonne when bought as salt for my pool.

The editor writes:

■ These prices – supplied by the UK’s Royal Society of Chemistry – were for elements in their purest available form. Some refining might be required.

This mouse model is ‘where the light is’

From Alec Cawley
Newbury, Berkshire, UK

Thank you for airing Joseph Garner’s views on the futility of trying to cure mouse “models” of human diseases (29 October, p 42). Please keep beating that drum. It crystallised worries I have had for a long time about engineered simulacra of human ailments. Researching these is so much like the drunk looking for their keys under the street light because “this is where the light is”. This is research being done because it is easy, not because it is useful.

From Geoffrey Patton
Silver Spring, Maryland, US

Your Leader article went a long way toward describing the challenges inherent in animal models of disease (29 October, p 5). Even well-designed studies comparing multiple doses and time points and exposing 50 or 60 animals to each dose can fail to predict effects seen in humans.

For another view, I recommend the book *Zoobiquity* by the cardiologist Barbara Natterson-Horowitz and science writer Kathryn Bowers (reviewed 16 June 2012, p 52). It lays out much of the marvellous continuity between other mammals and ourselves. We all evolved from a single ancestor and share commonality in many functions and genes.

While differences bedevil us, there is much yet to be learned about the failures and successes of animal models. Mouse courting songs going wrong when the “language gene” FOXP2 is messed up (29 October, p 14) underscores this interspecies correspondence between genetics and function.

Air pollution is worse inside cars and in dust

From Wiebina Heesterman
Birmingham, UK

Michael Le Page discusses combating air pollution from

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cars, but doesn't mention that air pollution inside cars is worse than that outside, where fumes are dispersed by the wind (29 October, p 16). A car interior may seem like a safe haven from air pollution, but chemicals emanating from the steering wheel, dashboard, armrests and seats mix with the pollution generated under the hood to form a brew of toxins for those sitting inside. In addition, fumes from the cars in front get in to air vents and remain trapped.

Surely the health risks are higher for children, who are still developing? Those who are driven to school face higher exposure than those who walk.

From Ian Napier
St Peters, South Australia

Le Page raises health concerns over direct emissions from motor vehicles. I wonder too about road dust, reported to represent 25 per cent of the particulates in the atmosphere.

How much of it is worn road surface and how much of that is tar – consisting of nasty chemicals including carcinogenic polycyclic hydrocarbons?

More reasons for an uncanny valley

From Krista Nelson
Rokeby, Tasmania, Australia

Laura Spinney describes the "uncanny valley" occupied by disturbingly not-quite-human images (29 October, p 28). I have long thought this effect was caused by sexual selection.

Subtle departures from the norm in an animal's appearance or movement can often be caused by genetic mutations or illness – which would render their bearers less than ideal mates.

I suspect only some experience the effect. Perhaps in the past those who discerned the uncanny valley helped the Neanderthals towards extinction for being human, but not human enough. Others may have helped bring Neanderthal genes into the *Homo Sapiens* genome.

From Roger Williams
Burradoo, New South Wales, Australia

Spinney notes that "incongruous eyes were particularly responsible for conjuring up eeriness" in the uncanny valley effect. People do seem to have a finely tuned sense of where others are looking; not just the direction, but at what distance the other is focusing.

If an android is otherwise almost indistinguishable from a person but the eyes don't look like they are focusing when pointing at you, the impression could be that there's nothing inside: rather as a zombie would be.

Keeling is not over for a long time yet

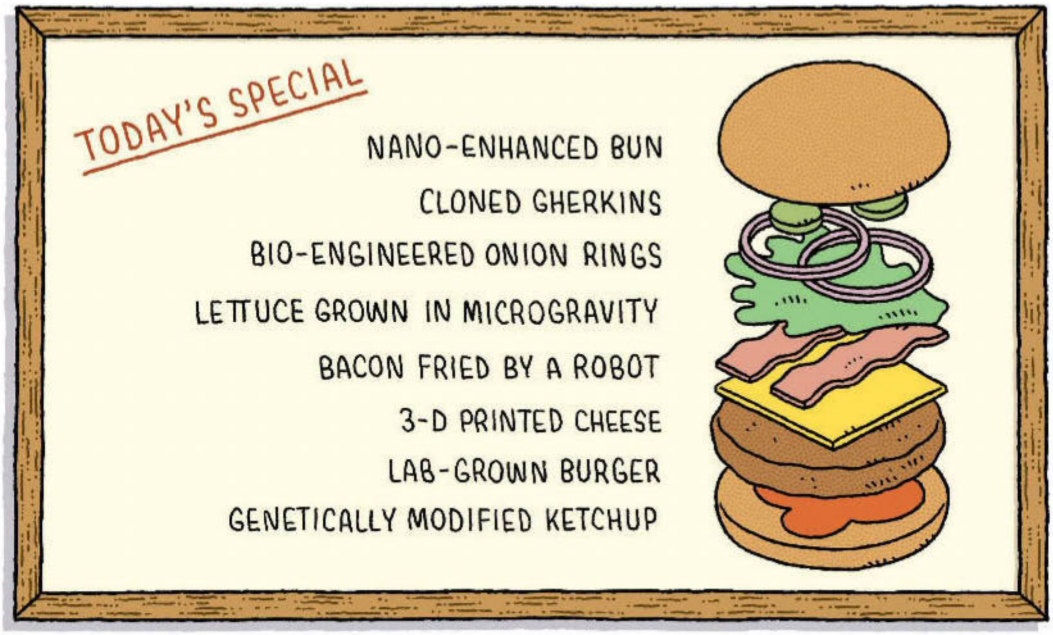
From Chris deSilva
Dianella, Western Australia

The "Keeling curve" isn't going to turn down any time soon, despite Perry Bebbington's wish to see effects of slowing carbon dioxide emissions (Letters, 8 October). It shows variations in concentration of atmospheric carbon dioxide, and will turn down only when CO_2 removed from the atmosphere by carbon sinks exceeds emissions – a very distant prospect.

The rate of increase in CO_2 concentration went up from 0.85 parts per million per year between 1960 and 1970 to 2.08 ppm/year between 2005 and 2015. This shows the sinks are working harder: the rate of increase is two-and-a-half times greater while emissions have increased fourfold.

Worryingly, it suggests that even if we reduced emissions to the levels of the 1960s we would still face an annual increase of 0.85 ppm/year, leading to CO_2 concentrations of 470 ppm before 2100. Cutting emissions wouldn't stabilise, let alone reduce, the atmospheric CO_2 concentrations.

TOM GAULD



Coming to UK TV: the Great British sun-dry-off

From Gwydion Williams
Coventry, West Midlands, UK

Looking for the origins of cooking, Graham Lawton noted the contradiction between the late evidence of human control of fire and the much earlier evidence that we were not eating raw meat (5 November, p 36). This overlooks methods of processing food that don't involve fire. Sun-dried meat, for example, is still widely eaten in hot climates.

I suspect that vegetables could also be processed quite a lot without using fire. Someone could organise a competition, to see what people could do without using anything our ancient ancestors would have lacked.

For the record

- **Wind-power generation in Ireland varied between 0 and 2000 megawatts in the week commencing 4 October 2016 (12 November, p 28).**
- **We're frothing: it is yeast that controls Philippe Parreno's installation at London's Tate Modern gallery (22 October, p 44).**

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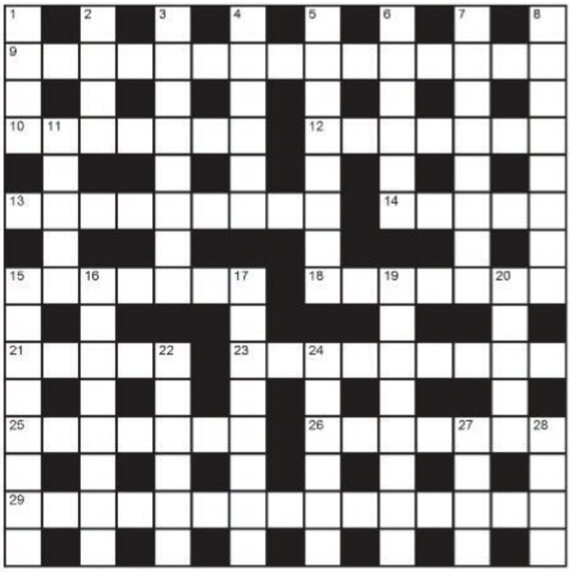
CROSSWORD

Compiled by Richard Smyth



Crossword No1

ACROSS

9 Chemical compound widely used as an insecticide (15)

10 Name given to certain species of baleen whale (7)

12 Thomas ___ (1757-1834), Scottish engineer, best known for the Menai Bridge in Wales (7)

13 References to other work (in scientific papers and so on) (9)

14 A group of apes, baboons or lemurs (5)

15 Old term for a painkilling drug (7)

18 The ___, 1623 work by Galileo Galilei (7)

21 Paul ___ (1902-84), British theoretical physicist (5)

23 In a fraction, the integer placed above the line (9)

25 A completed loop, in electronics (7)

26 In geometry, lozenge or diamond-shaped (7)

29 Program that manages a computer's software and hardware (9,6)

DOWN

1 Niels ___ (1885-1962), Danish physicist (4)

2 Jelly-like substance often used in microbiological experiments (4)

3 California city, noted for its many manufacturing businesses and small population (8)

4 US human spaceflight programme launched in 1961 (6)

5 Ocean region beneath which the Viking Gas Field was discovered in 1965 (5,3)

6 In computing, a small application - often a plug-in - that performs a specific task (6)

7 The science of classification (8)

8 Aluminosilicate mineral that makes up more than half of Earth's crust (8)

11 Constellation in which the stars Betelgeuse and Rigel can be seen (5)

15 In the human body, a muscle that draws towards the centre of the body or limb (8)

16 Mechanical models of the solar system (8)

17 "___ was a giant. His head was in the clouds, but his feet were on the ground" - Richard Feynman (8)

19 Red-striped form of the mineral chalcedony (8)

20 Bacterium that can cause severe food poisoning in humans (1,4)

22 Concerned with actions and their consequences (6)

24 An optical illusion - or a French combat aeroplane (6)

27 Second letter of the Greek alphabet; a form of radiation; a software prototype (4)

28 Galaxy cluster some 330 million light-years from Earth (4)

Answers with the next crossword

We would love to hear what you think of the first *New Scientist* crossword. Please email us at letters@newscientist.com and let us know if you'd like to see more, whether it was too hard or too easy, or any other comments about the game.

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PAUL MCDEVITT

OUR colleague returned from the US with a bottle of Essentia Water, an "exceptionally pure, smooth tasting" variety that regales drinkers with the thrilling gambit that every bottle is "9.5 pH or higher".

Purified Essentia Water comes with added sodium bicarbonate and dipotassium phosphate, and the label takes pains to assure us these electrolytes are "added for taste" and certainly not, say, because the first additive has a pH of 9.5 and the second acts as a buffer.

Those tempted to take a sip but worried the contents might be more alkaline than Toilet Duck unfortunately have no recourse to safety: the label explains matter-of-factly that the alkaline water is "too pure to be tested by pH strips".

Those about to play a bleach-themed game of Russian roulette with their mouth will take little comfort in the motivational aphorism plastered on the company's Facebook page: "mistakes are proof that you're trying".

PREVIOUSLY we discussed the potential of leaving a post-mortem status update to brief your social network after you've shuffled off this mortal coil (5 November).

Little did we realise that Facebook had performed a test run of the technology. For a brief interval on the afternoon of 11 February, many visitors to the social network discovered that they had died. Even Facebook founder and CEO Mark Zuckerberg had passed away.

But reports of a mass die-off had been greatly exaggerated, a statement issued by the company said afterwards. A glitch in the matrix, or a grim vision of what 2016 had in store for us?

WARMING to the challenge of final status updates is Sarah Jenkins, who thinks that Anatoli Petrovich Bugorski, the Russian scientist who famously survived a strike by a particle accelerator beam in 1978, might announce his passing with the posting: "I regret to announce, I am now a past particle".

OUR colleagues in the news section discuss carbon nanotube-laced spinach plants that detect explosives, concluding that "eventually it could be possible to sow seeds across a site suspected of containing landmines and use the plant detection system to locate them" (bit.ly/ns_spim).

Ian Napier writes "Might the reason for this not yet having been tested be down to a lack of volunteers willing to undertake the sowing process?" What is needed, we think, is a plant that shows where in a minefield it's safe to sow the spinach. And, er, a plant that shows where it's safe to sow that one, and…

OFTEN we find beauty products hiding behind vague promises of benefit, so it's pleasing to see a company prepared to name specifics. Chris Smith was browsing through the *High Life* magazine given out to British Airways passengers recently when he spied an advert for an eye cream that promises "138% improvement in skin firmness in 28 days".

Chris doesn't mention the cream maker's name, and our research has met stony silence, but may we hazard a guess at "Medusa incorporated"?

ALSO pondering commercial messages is Ian Gordon, who recalls two television adverts that would run consecutively with an unfortunate clash of straplines. "The products were anti-inflammatory Voltarol 'The joy of movement', and laxative Senokot 'Restore your natural movement'." Perhaps some advert scheduler just has a sense of humour.

FEEDBACK previously furrowed its brow over the necessity of a company devoted to selling only odd socks (5 November). Mark Dowson recalls a colleague working at MIT in the 1960s who always wore odd socks.

When asked why, he explained that reaching into a drawer of numerously coloured single socks, he was "much more likely to retrieve an odd pair than a matching pair, so it saved valuable time." So the next time your boss complains about your scruffy attire, just tell them it's one the habits of highly effective people.

BILL BARKSFIELD tells us that despite all the missives, he couldn't let the latest case of nominative determinism slip past him. "In a talk at the Newcomen Society in London about the history of mobile phone networks, with a perfectly straight face, the lecturer revealed the inventor of the cellular network at Bell Telephone was none other than Douglas H. Ring."

FRENCH scientists are investigating how on earth some people don't like cheese (5 November).

Ian reappears in our inbox to say that as scans showed the brain's reward centre lighting up in response to cheese, even in those who profess to hate it, the study "isn't worthy of further investigation, since it just means we've found a tool to detect those who find pleasure in abstinence".

Evidence of a piety gland? Feedback thinks it would certainly be worth looking into a test to find the saintliest among us.

> "After querying my order for dog food from Devoted Pet Foods in Tamworth," says Bel Goldie-Morrison, "my answer from the 'Devoted Team' came from none other than Laura Kibble."

You can send stories to Feedback by email at feedback@newscientist.com. Please include your home address. This week's and past Feedbacks can be seen on our website.

Ocean dwellers

Has any thought been given to the idea of building cities on the sea? Surely the technologies exist to make this a realistic alternative to destroying more agricultural land, and it could even allow us to benefit from sea level rise.

■ This idea has been around since the early 1960s, when architect Richard Buckminster Fuller designed a tetrahedron-shaped floating city intended for Tokyo Bay. But it's only now that floating habitats are nearing reality.

PayPal co-founder Peter Thiel is a backer of the Seasteading Institute, which plans to get a modular floating city costing $170 million on the water by 2020. French architect Jacques Rougerie has designed a 900-metre-long, manta-ray-shaped floating city that would house 7000 people. And Vincent Callebaut from Belgium envisages a lily-pad-shaped city that could accommodate 50,000.

> "Richard Buckminster Fuller designed a tetrahedron-shaped floating city intended for Tokyo Bay"

The main issue holding back these ideas is the amount of money required to build them. Until this funding is secured, we will have to be satisfied with huge cruise liners that have almost become floating cities themselves.

Peter Hassall
Wellington, New Zealand

I know that face

I've seen several archaeological shows in which skulls are built up to create faces. How valid is this? Has anyone tested the procedure on a modern skull and compared the result with a photograph of the person?

■ Having developed the Manchester Technique of Forensic Facial Reconstruction at the University of Manchester in the UK between 1973 and 1980, I can confirm that it is perfectly valid. The face will emerge from the cast of a skull as you add the muscles and facial structures with clay or wax, using average soft-tissue measurements as a guide.

The technique was put to the test when I began assisting police with their investigations into the identity of human remains. Using this method, approximately 60 per cent of the individuals were recognised. In these instances, a reconstruction could be checked with an image of the subject. Once a name was provided, more-conventional techniques could be applied to confirm the identity.

Although such studies would never result in an exact portrait, they would routinely generate a face similar enough to the subject's that their identity could be ascertained. By today's standards the approach may seem simplistic, but this was before DNA testing became available.

I've also undertaken studies on casts of the skulls of living people created using scanning technology. A similarity with the subject can always be observed. Although this work was regarded with suspicion when it started in the 1970s, today it can be studied at degree level.

Richard Neave
Rye, East Sussex, UK

Terracotta solder

I put a piece of damp terracotta into my brown sugar to keep it crumbly. Why does the same treatment make icing sugar fuse into a solid brick?

■ Brown sugar is a mix of crystalline sugar and up to 10 per cent molasses, a brown syrup obtained during refining. Soft brown sugar is moist owing to the hygroscopic (water-absorbing) properties of the molasses. If this water evaporates, the sugar hardens. To prevent this, you can add damp terracotta, a few marshmallows or a slice of bread to supplement the moisture.

Icing sugar is an entirely different kettle of fish. It is a finely ground sugar that, because of its small particles, is prone to clumping if it gets moist. Such highly refined, granulated sugars have a water content of around 0.05 per cent and contain anti-caking agents such as calcium phosphate to absorb moisture and prevent clumping. The correspondent's damp terracotta overcame the anti-caking agent, so the sugar particles clumped, then crystallised together.

Experienced bakers know that success depends on using the right sugar for each job. That's the way the cookie crumbles.

David Muir
Edinburgh, UK

Lunar lift

Tides are affected by the moon's gravity. So does your weight change depending on its position?

■ Absolutely. The weight of any object is the sum of the attraction between it and every other body in the universe, according to their various masses and positions. This greatly complicates all sorts of measurements. For instance, in the 18th century, the French astronomer Nicolas Louis de La Caille made sophisticated measurements in South Africa of the shape of Earth's southern hemisphere, concluding that it was flattened. He did not realise that he should have made these measurements on a wide open plain. His readings were badly distorted by the gravitational masses of Table Mountain and the Piketberg mountain range, and it was some time before anyone corrected the shape he calculated.

As the moon passes above, to the west, below and to the east of us, we get lighter, lean to one side, get heavier, then lean to the other side, respectively. But its mass is so far away that if I were to swing a pin on a silk thread, it would affect my apparent weight more strongly than the moon does.

Jon Richfield
Somerset West, South Africa

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